Improving Surgical Patient Flow in a Congested Recovery Area

By
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B.S. in Operations Research and Engineering, Cornell University, 2007

Submitted to the MIT Sloan School of Management and the Mechanical Engineering Department in Partial Fulfillment of the Requirements for the Degrees of
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and
Master of Science in Mechanical Engineering

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Massachusetts Institute of Technology

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Abstract

The recent movement in healthcare reform requires hospitals to care for more patients while simultaneously reducing costs. Medical institutions can no longer afford to simply add beds and hire staff to increase capacity. They must use existing resources more effectively and develop innovative solutions to increase capacity.

This project focuses on the redesign of surgical patient flow through multiple Post-Anesthesia Care Units (PACUs) at Massachusetts General Hospital (MGH). The PACU is where surgical patients recover following their procedure that takes place in the Operating Room (OR) suite. Some patients experience delays when leaving the OR due to the lack of a staffed PACU bed. These patients begin the recovery process in the OR which causes delays for to-follow cases. In addition, the OR nursing staff rather than a PACU nurse must monitor recovery, which drives higher costs and frustrates staff members. Therefore this study examined the sources of delay and sought to redesign the flow of surgical patients through the PACUs.

Our main recommendation is to incorporate a "Fast Track" for the outpatient population that eliminates delays and expedites outpatient processing in the PACU. Segregating the outpatients and implementing the one-stop "Fast Track" recovery process will reduce average outpatient PACU length of stay (length of stay) by 27%, the equivalent of adding 1.8 beds of capacity. Through the application of operations management techniques, we can decrease the patient processing time or length of stay in the PACU, which in turn increases throughput and creates additional capacity.

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Chapter 1: Introduction

1.1 Background

Waiting and delays in healthcare delivery systems have become so common that patients and providers have accepted them as inevitable when receiving care (Haraden & Resar, 2004). These undesirable effects are often believed to be a result of an extremely complex system with inherent unpredictability. To address these problems, hospitals have traditionally responded by increasing capacity with additional resources to buffer these delays (i.e., increasing the number of beds and staff). However, adding more resources has come at a cost. Historically, these costs have been built into the prices for each service provided and passed on to the insurer of the patient and indirectly onto the patient.

Recent healthcare reform legislation, namely the "Patient Protection and Affordable Care Act," calls for a transition from this pay-for-service system to one with bundled payments (United States Congress, 2010). Under bundled payments, healthcare institutions would receive a single pre-determined fee for a patient's entire care episode rather than payment for each individual treatment or service received (Emanuel, 2011). Another initiative, known as global payments, would have hospitals receive a single fee for a patient's total care across multiple episodes or surgical visits to the hospital. As the healthcare industry moves from a fee-for-service payment system to bundled and global payment systems, the hospitals must find new ways to increase capacity without adding cost.

Healthcare institutions have begun to take an alternative approach to increasing capacity through additional resources. By pursuing innovative solutions to use existing infrastructure more efficiently, hospitals have been able to increase capacity and improve the patient experience with the same resources. Massachusetts General Hospital (MGH) is a leader in investigating opportunities to use existing capacity more efficiently.

1.2 Massachusetts General Hospital

MGH is the third oldest general hospital in the United States and the oldest and largest hospital in New England. It consistently ranks among the top five hospitals in the nation by *U.S. News and World Report*, which currently ranks MGH as second in the U.S. and first in the metro Boston area (Massachusetts General Hospital, 2012). MGH's main campus, located in Boston's West End, has over 50 operating rooms and over 900 patient beds. Approximately 35,000 surgical cases ranging across 16 different services are performed each year. In addition, MGH is an academic hospital and is the oldest and largest teaching hospital for the Harvard Medical School. MGH is world-renowned for its quality of care and is a leader in clinical research. Its annual research budget of nearly $550 million is the largest in the country.

1.3 Project Overview

Following surgery, a patient begins the recovery process in a Post Anesthesia Care Unit or PACU before being transported to a hospital bed or discharged home. The PACUs at MGH have limited resources (beds and clinical staff) to care for the patients recovering from surgery. If a surgical case concludes and there is not a bed or nursing staff available to care for the patient in the PACU, the patient begins the recovery process in the operating room. This delay ties up the operating room as well as the clinical staff assigned to that room causing to-follow cases to be delayed or even cancelled. These "PACU Delay Events" result in sub-optimal surgical patient flow. In addition, these delays frustrate the clinical staff and negatively impact revenue for the institution.

Rather than simply increasing PACU resources, we sought to increase capacity through improved operational efficiency and increased patient throughput. By developing policies and procedures to get patients through the PACU quicker, we can reduce the length of stay, which will free up resources and reduce delay events. There is also a financial impact for excessive PACU length of stay. Due to the continuous monitoring required in the PACU, the cost for a two-hour PACU stay is roughly equivalent to a 24-hour hospital stay (Waddle, Evers, & Piccirillo, 1998). Therefore, reducing PACU length of stay provides both operational and financial benefits to the institution. Initial analysis of PACU length of stay data at MGH revealed substantially longer lengths of stay at MGH than at peer hospitals. We sought determine what aspects of the system design were driving the longer PACU stays at MGH.

The focus for this study was primarily on the outpatient population. Outpatients are those who are discharged home following surgery; they do not go to a hospital floor bed for an overnight stay. This population was chosen for a few reasons. First, these patients were not directly affected by the downstream hospital bed bottleneck. The lack of available hospital beds is the primary cause for *inpatients* to be delayed in the PACU. Reducing PACU processing time for inpatients yields no benefit, as these patients must remain in the PACU until a hospital bed is available. Other initiatives were underway to address this system constraint, such as the surgical scheduling optimization project discussed earlier. Our goal was to develop improved processes for the outpatient population, which can be transferred to inpatients once the hospital bed bottleneck has been addressed. A follow on project will address intra-day surgical scheduling to level PACU patient volumes throughout the day.

In addition, using this population allowed us to benchmark against outpatient surgery centers that were designed for efficient patient processing. One of MGH's satellite surgery centers, Massachusetts General West Orthopedic Ambulatory Surgery Center (MGWest), was analyzed extensively to capture best practices and lessons learned in a high throughput environment. Initially, we focused on the orthopedic outpatient population on MGH, later expanding to encompass all outpatients.

Comparing the PACU system at MGH to the MGWest benchmark revealed two major drivers for delay in processing outpatients through the MGH PACUs. The MGH PACUs were all mixed population PACUs housing both inpatient and outpatient recoveries. Nurses typically care for two patients simultaneously, often one inpatient and one outpatient. Since inpatients require more attention than outpatients, nurse availability to outpatients leads to processing delays. The other major cause of delays was the two-step recovery process that was implemented with the opening of the Lunder building in August 2011. Separating phase 1 and 2 recovery across two locations and two nurses requires an additional handoff and patient transportation. The patient is not progressing towards discharge during the transition from one PACU to another, which further extends the total PACU stay for the patient.

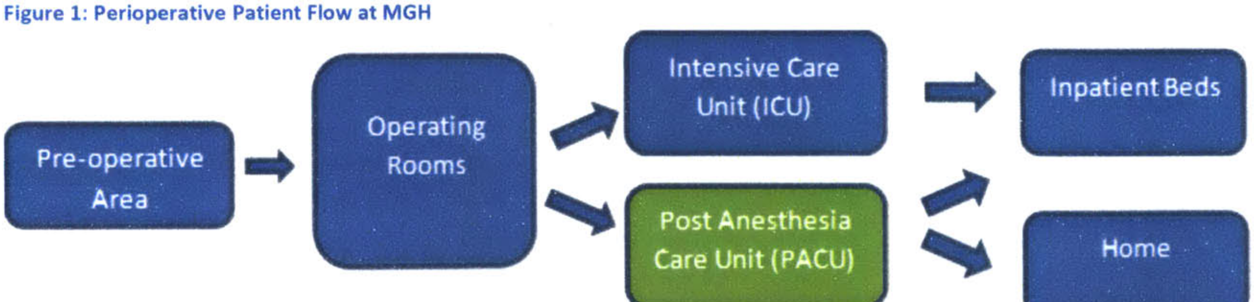
1.4 Description of Perioperative Services at MGH

The Perioperative Services department at MGH is responsible for managing the flow of surgical patients. Every step from when a surgery is booked, through the surgery, and until the patient is discharged, either home or to an inpatient bed, is part of the patient's perioperative stay. In other words, the perioperative unit encompasses all of the services provided to the patient before, during, and immediately after surgery.

Figure 1 shows the patient's flow on the day of surgery. Prior to the day of surgery, the Preadmission Testing Area within Perioperative Services determines if the patient is healthy enough to have the surgery. On the day of surgery, the patient either arrives from home and checks in or is brought down to the surgical floors from an inpatient bed. Next, the patient is prepared for surgery in a pre-operative area. Here, the patient's vital signs are taken, and he or she is prepped for anesthesia. The patient is then moved to the operating room where he or she is anesthetized and the surgery is performed. When the surgery is complete, most patients are transported to the PACU for recovery. Critical patients recover in an Intensive Care Unit (ICU).

In the ICU or PACU, the patient awakes from the anesthesia and begins the recovery process. In most cases, patients are cared for until they meet clinical discharge criteria[8]. Once they have met these criteria, patients are discharged from the ICU or PACU to either a hospital bed for a multiple day recovery (inpatient) or directly home (outpatient). A patient's *perioperative* stay concludes when he or she is discharged from the ICU or PACU.

Figure 1: Perioperative Patient Flow at MGH



[8] Discharge criteria are specific vital sign levels that are governed by American Society of PeriAnesthesia Nurses (ASPAN) standards.

1.5 Definition of PACU Delays

PACU delay events at MGH are recorded when a patient is ready to depart the operating room, but cannot be received in the PACU due to the lack of available resources (i.e., physical bed and nurse). As a result, the patient begins the recovery process in the operating room and remains there until the PACU has available capacity to receive the patient. This occupies both the operating room and the clinical staff assigned to that room. These delays cause to-follow cases to be delayed or cancelled. Implementing the proposed "Fast Track" solution will increase capacity of the PACU to minimize the occurrence and duration of these delay events.

1.6 MGH - MIT Collaboration

Over the past five years, MGH has formed a partnership with the Massachusetts Institute of Technology (MIT), specifically with the Operations Management group in the Sloan School of Management and the Leaders for Global Operations (LGO) graduate program. The Perioperative Services group at MGH has led this collaboration with projects ranging from surgical scheduling optimization to process improvements in the Preadmission Testing Area and the ICU. This ongoing collaboration has delivered phenomenal results.

This study on PACU throughput follows another recent project on surgery scheduling. The surgical scheduling optimization project led by Dr. Peter Dunn and Bethany Daily of MGH, and Professor Retsef Levi, Timothy Carnes, and Devon Price of MIT, proposed changes to the operating room schedule in order to level out the surgical patient census in the hospital and provide open blocks for scheduling non-elective surgeries (Price, 2011). This project sought to understand what was causing the hospital census to reach capacity in the middle of the week and improve surgical patient flow by decreasing this mid-week peak. It was selected because the hospital census was the most prominent bottleneck in the surgical patient flow process. Once this project moved toward implementation, the team chose to investigate the PACU, which functions as a buffer between the operating rooms and the hospital floor beds[9].

1.7 Project Approach

The first step to improving patient flow through the PACU is understanding to what extent current practices are constraining patient flow in the system. We begin by analyzing PACU length of stay data at

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[9] This project was performed within MGH IRB and MIT COUHES guidelines.

MGH. This data is compared to internal and external benchmarks to characterize the current state of PACU performance. Once the opportunity is characterized, the next step is to determine how to improve performance. For this, we focus on our internal benchmark, MGWEST. We identify the specific steps in the PACU process that are the sources of delay, through an observational time study performed at MGH and MGWest.

Next, a root cause analysis determines why particular steps in the process take longer at MGH than at MGWest. Only after the root causes are identified are we able to develop a solution that addresses these sources of the delay in the system. A proposed outpatient "Fast Track" solution is defined and modeled using discrete event simulation. First, a baseline model, reflecting the current system, is created and validated against actual data from November 2011. After validation, the model is used to quantify the benefits of the "Fast Track" and test for feasibility given the physical capacities of the PACUs. In addition, various what-if scenarios are run with different staffing levels to predict performance. Finally, we identify a final set of recommendations for implementing the outpatient "Fast Track" along with the challenges and next steps.

Chapter 2 will characterize the current situation of PACU operations and the PACU patient length of stay distribution. We first analyzed a data set from 2010 to build a baseline characterization, and then proceeded to further investigate through observations in the summer of 2011. In Chapter 3, we will perform a root cause analysis to identify the process gaps, which are driving delays in PACU lengths of stay. An observational time study performed at MGH and MGWest is the primary source of data for this comparison. Chapter 4 will discuss a proposed solution to address the root causes of delay and walk through the development and results of a discrete event simulation to validate this solution. Chapter 5 summarizes the final recommendations and provides an implementation plan with immediate next steps.

Chapter 2: The MGH PACUs – Performance Assessment

2.1 Description of PACUs at MGH

MGH has multiple PACUs that service different types of patients. In August 2011, the new Lunder building, which houses new operating rooms and PACUs, was opened at MGH. This led to many changes including some major ones in the configuration of the PACUs and the way post-surgery patient flow is designed. This occurred in the middle of the internship that ran from June through December of 2011. Therefore two different current states were analyzed as the environment changed in the middle of the internship. Initially, MGH had four PACUs, all operating as single-step recovery locations[10]:

1. Wang 3 PACU: Primarily outpatient recoveries
2. PEDI PACU: Only pediatric patient recoveries, both inpatients and outpatients
3. Ellison 3 PACU: Inpatients, outpatients and overnight patient recoveries
4. White 3 PACU: Primarily inpatient recoveries

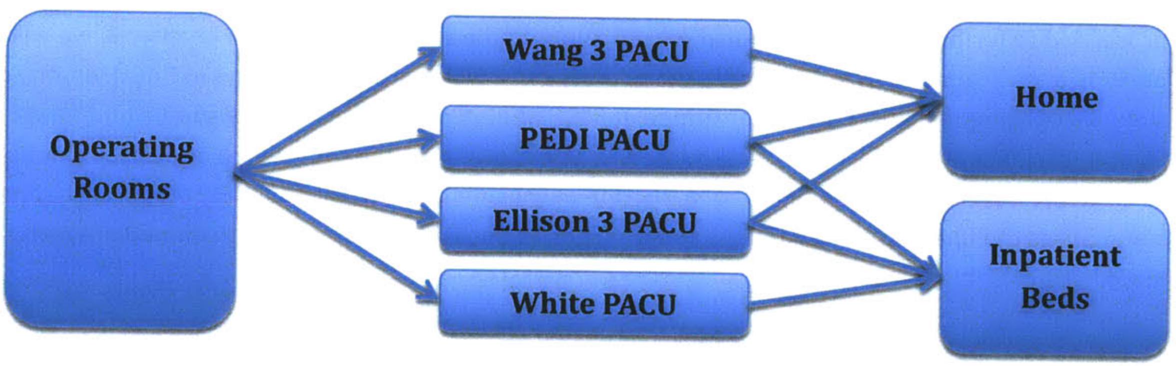

Figure 2: PACU Patient Flow before Lunder Building opened in August 2011

When the Lunder building opened in August of 2011, new PACUs were opened and the old PACUs were reorganized, which changed the current state of the PACUs. Due to capacity constraints, a two-step recovery process was put in place for outpatients. Initial recovery (phase 1) is performed in one of the primary PACUs and then the patient is transported to the Center for Perioperative Care (CPC) for final recovery (phase 2). This two-step process was considered a necessity with the physical capacities of the primary PACUs. After August of 2011, the PACUs were configured as follows:

1. Lunder 2 Perioperative Unit: Inpatient and outpatient phase 1 recoveries.
2. Lunder 4 Perioperative Unit: Inpatient and outpatient phase 1 recoveries.
3. Ellison PACU: Inpatient and outpatient phase 1 recoveries. Also pediatric and overnight care patient recoveries.

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[10] Patients visited one PACU to recover before being discharged to the floor (inpatients) or home (outpatients)

4. White PACU: Inpatient and outpatient phase 1 recoveries.
5. Center for Perioperative Care (CPC): Phase 2 recoveries for all outpatients[11].

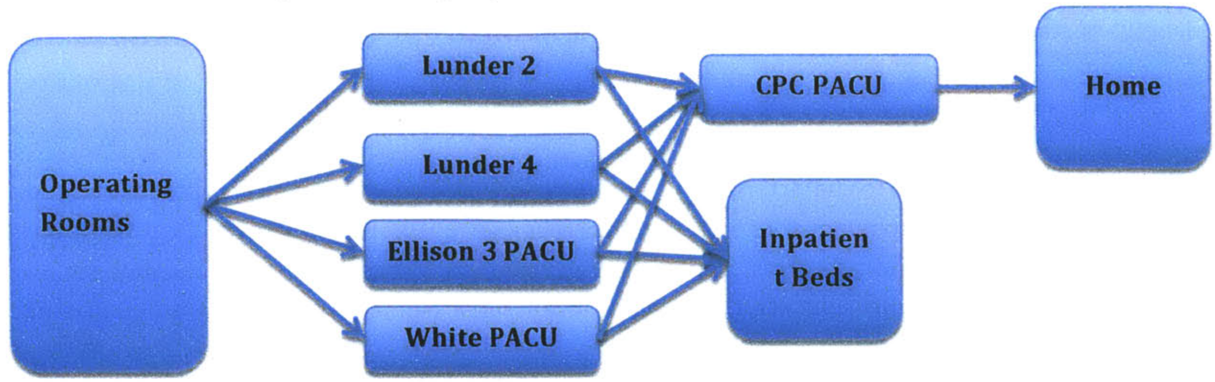

Figure 3: PACU Patient Flow after Lunder Building Opened in August 2011

The opening of the new building and reconfiguring of the PACUs dramatically altered the PACU performance with regard to patient length of stay. A great deal of learning had to take place, as nurses were reassigned and the new two-step outpatient recovery process was implemented. The two-step process for outpatient recoveries separates what had been a fluid recovery with a single nurse in one location, to a disjointed process across two locations with a handoff between two nurses[12].

The opening of the Lunder building in August 2011 and corresponding changes to PACU patient flow altered the current state of PACU operations. The initial current state characterization discussed in this chapter reflects PACU performance in 2010, before these changes were in effect. The statistical analysis within this chapter reflects the opportunity for PACU length of stay improvement prior to the changes in the PACU system. While this analysis does not reflect the current PACU operations after August 2011, it serves as a useful baseline for characterizing potential length of stay improvement. In general, the process for outpatient recoveries became more inefficient as the new configuration required a two-step process in fully mixed-population PACUs.

2.2 Methods

Several methods are used to build the full picture of PACU performance and determine the opportunity for improvement. Observations build a fundamental understanding of the PACU process and challenges

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[11] There is no phase 2 PACU recovery for inpatients as this entails preparing the patient for discharge from the hospital.

[12] The two-step recovery process for outpatients was necessary because the Center for Perioperative Care (CPC) did not have the resources (primarily anesthesia coverage) to perform Phase 1 recoveries and the Phase 1 PACUs did not have the capacity to hold patients through discharge.

associated with surgical patient flow. Next, we use data analysis to characterize the length of stay performance of the PACUs at MGH. This includes building a linear regression model to compare the lengths of stay experienced at MGH PACUs to those at MGWest.

2.2.1 Data Collection

The primary data set used to characterize PACU performance consists of all surgical cases that visited one of the MGH PACUs from January 1st 2010 to December 31st 2010. This equates to 29,126 PACU visit records. A full calendar year of data is used in order to capture any seasonal effects. The data set included patient characteristic data (e.g. age, acuity level), surgical procedure data (e.g. surgeon, surgery length), and time stamps tracking the patient progression from check-in, through surgery, to PACU departure.

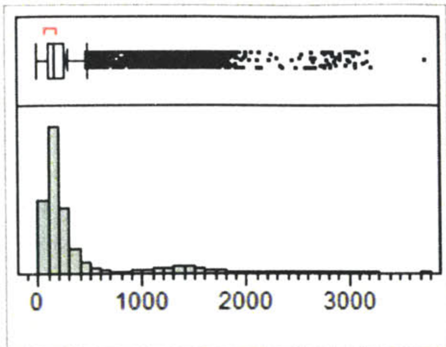
Three different data sources are used to build the data set. The majority of the data came from the operating room scheduling and PACU patient management systems. The third source, an online database of surgical case data, was used to obtain the procedure type for each case. Procedure type is categorized by a four-digit International Classification of Diseases book 9 code (commonly referred to as ICD-9 codes). Once this data set was assembled, the PACU length of stay data was statistically analyzed and compared against benchmark institutions. Observations provided confidence in the length of stay data. Arrival and departure times were recorded accurately. The same was not true for a "ready to depart" time stamp and for this reason we chose not to use this time stamp in our data set. See appendix 6.1 for an example data set.

2.3 Results

2.3.1 Statistical Analysis

The primary statistic of interest was PACU length of stay. We began by analyzing the population of surgical patients who visited the PACU in the calendar year 2010. Figure 4 provides summary statistics. The average PACU length of stay, overall, for both inpatients and outpatients was 286 minutes or 4.77 hours, with a standard deviation of 370 minutes (6.2 hours). The data has a positive skew with long tail to the right of the mean. Since large values influence the mean, the median and quartiles provide a more accurate picture of actual PACU performance. The median PACU length of stay experienced at MGH in 2010 is 162 minutes or 2.7 hours, and the 25% and 75% quartiles were 109 minutes (1.8 hours) and 260 minutes (4.3 hours), respectively.

Figure 4: JMP Statistical Software distribution analysis output for PACU length of stay data (min) from 2010 Surgical PACU Patients



Quantiles

100.0%	maximum	3769
99.5%		1754.83
97.5%		1489
90.0%		554
75.0%	quartile	260
50.0%	median	162
25.0%	quartile	109
10.0%		76
2.5%		42
0.5%		20
0.0%	minimum	0

Moments

Mean	286.27875
Std Dev	370.02412
Std Err Mean	2.1681515
Upper 95% Mean	290.52843
Lower 95% Mean	282.02908
N	29126

*X-axis unit is minutes

2.3.2 Benchmark Comparisons

2.3.2.1 External Comparators

Once we had characterized the PACU performance at MGH, the question became how it compared to that of other institutions. To answer this question, we turn to the Surgical Profitability Compass, an online database of hospital data built by The Advisory Board Company[13]. This database compares average PACU length of stay by procedure type at MGH against a cohort of comparison institutions. MGH PACU length of stay performance for the top 10 ICD-9 procedures with the highest volume at MGH is compared against all academic facilities and hospitals with 26-50+ operating rooms. In almost all comparisons, the average PACU length of stay experienced at MGH is at or below the 25th percentile of performance within the cohort (The Advisory Board Company, 2011). This is true for both inpatient and outpatient procedures, as the top 10 procedures by volume for each category were compared. This indicates that there is indeed room for improvement. Since the Surgical Profitability Compass only provided very high-level data, an internal comparator facility was better suited to be used as a benchmark for detailed analysis.

2.3.2.2 Internal Comparator: MGWest

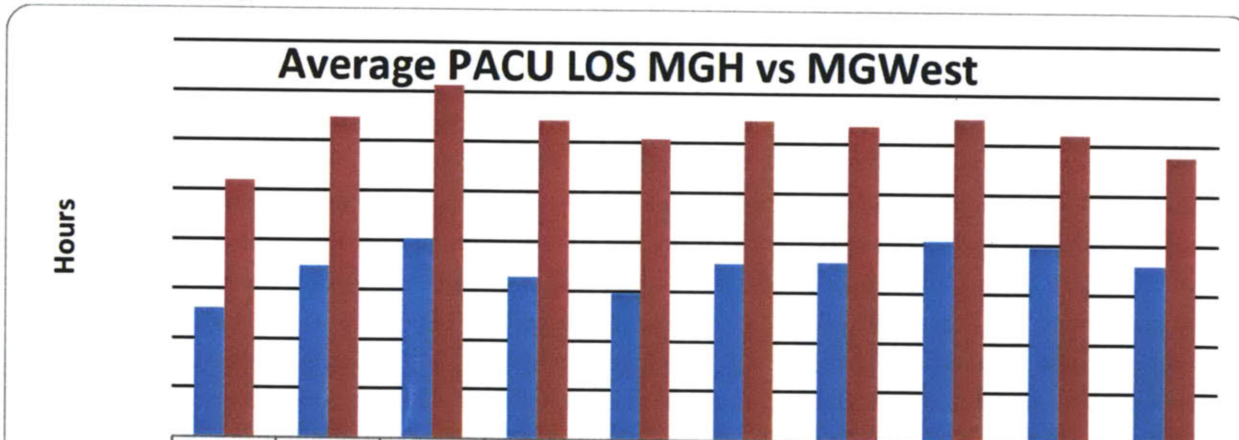
The Massachusetts General West Orthopedic Surgery Center (MGWest) located in Waltham, MA was chosen as a strong internal comparator. Many of the same orthopedic surgeons operate at MGH and MGWest and perform the same procedures on similar patient populations. Since MGWest is an outpatient surgery center, there are specific requirements as to the type of patients it can service. In general, less complex cases can be performed at either MGWest or MGH, while the more critical cases

[13] The Advisory Board Company is a global research, consulting, and technology firm helping hospital and university executives to better serve patients and students (The Advisory Board Company, 2012).

can only be done at MGH. Therefore, our analysis is based only on the MGH patient population that could have had surgery at MGWest. Cases with patient characteristics or procedure types that could not have had surgery at MGWest were removed from the data set[14].

To account for surgeon or procedure specific differences, the average PACU length of stay was calculated for each surgeon-procedure pair at each surgical site. The average PACU length of stay at MGH and MGWest were compared when the same surgeon performed the same procedure on similar patient populations. Figure 5 below displays the top 10 surgeon-procedure pairs by volume with the greatest difference in average PACU length of stay across the two sites. In most cases, the average PACU length of stay at MGWest was 1-1.5 hours shorter. This indicates that the PACU length of stay performance is tied to the PACU operations at each site. Although this paints a pretty clear picture as to the opportunity that exists to create more efficiency, there could be other factors in play that are influencing PACU length of stay. The linear regression discussed in the next section captures the true contribution that surgical site has on PACU length of stay.

Figure 5: Average PACU length of stay at MGH and MGWest (2010 Data: Orthopedic Outpatients discharged Home with < 8 hour PACU length of stay)



	Dr. A OP RED-INT FIX RAD/ ULNA 7932	Dr. B DESTRUC-SHOULDER LES NEC 8081	Dr. C CRUCIATE LIG REPAIR NEC 8145	Dr. B SHOULDER ARTHROPLA ST NEC 8183	Dr. C SHOULDER ARTHROPLA ST NEC 8183	Dr. D SHOULDER ARTHROPLA ST NEC 8183	Dr. D ROTATOR CUFF REPAIR 8363	Dr. C ROTATOR CUFF REPAIR 8363	Dr. E ROTATOR CUFF REPAIR 8363	Dr. B ROTATOR CUFF REPAIR 8363
MGWEST	1.3	1.7	2.0	1.6	1.5	1.8	1.8	2.0	2.0	1.8
MGH	2.6	3.2	3.6	3.2	3.0	3.2	3.2	3.3	3.1	2.9

2.3.3 Regression Analysis

Several factors could potentially affect the total amount of time a patient spends in the PACU. Patient characteristics such as age and acuity level as well as procedure type, surgeon, surgery site, and surgery

[14] Requirements for MGWest: Discharged Home from PACU, Orthopedic Cases only, Patient Acuity Level (ASA Score) I &II only, PACU LENGTH OF STAY < 8 hrs.

length all influence a patient's PACU length of stay. Linear regression analysis allows us to determine the effect each individual contributing factor has on PACU length of stay, when all other factors are held constant. Once again, case data from January 1st 2010 to December 31st 2010 is the basis for analysis.

In particular, we are interested in the effect the surgery site (MGH vs. MGWest) has on PACU length of stay. Therefore, the data set that is the basis for the linear regression is limited to only those case records that could have been performed at either MGH or MGWest. Any case done at MGWest can be performed at MGH; so all MGWest cases were included. The same is not true for all cases done at MGH. As previously noted, MGWest only has the capability to service routine procedures on relatively healthy patients. This is primarily due to the fact that there are no inpatient beds at MGWest to care for a patient overnight. Therefore, only case records from MGH that meet the MGWest criteria[15] are included in the data set.

The linear regression predicts PACU or post-operative length of stay controlling for patient age, patient acuity level, procedure type, surgeon, and surgery site and surgery length. The regression method used is forward stepwise, with the stopping rule of minimum Akaike Information Criterion[16] (AIC). In this method, factors are added to the regression one by one until the minimum AIC level is reached. Similar results were obtained in a stepwise backward regression, in which all factors are initially included and then removed one by one until the minimum AIC level is reached. In addition, a K-fold cross validation with a K-fold factor of five produces similar results. In K-fold cross validation, the data set is broken into 5 subsets. The model is built based on four of these subsets and then validated against the fifth. This is repeated for each of the five subsets and the model with the greatest K-fold RSquare value is selected (i.e., best fit). This method allows us to validate the model against data that is not used in the construction of the regression. The table below summarizes the results from the AIC and K-fold cross validation regression methods. The RSquare values indicate that approximately 45% of the variation in the PACU length of stay data is captured by the model. Both methods produced statistically significant models (Prob > F is less than .0001) with K-fold cross validation yielding a higher overall F ratio which indicates a slightly better fit.

Table 1: Regression output statistics from JMP statistical software.

Method	Rsquare	Rsquare Adj	F Ratio	Prob > F
AIC	0.46	0.45	68.54	<.0001
K-Fold	0.46	0.45	81.29	<.0001

---

15 MGWest criteria corresponds to orthopedic outpatient cases with a PACU LENGTH OF STAY < 8 hours and patient acuity level (ASA score) of I or II.

16 Akaike Information Criterion is a measure of the relative goodness of fit of a statistical model. For validation purposes the stepwise regression was also run using the Bayesian Information Criterion (BIC) and similar results were obtained.

Using these regression models, the individual effect of each input factor is determined. The two most significant factors are surgical site and surgery length[17]. Table 2 summarizes the effect of each factor. When all other factors are controlled for, the difference in PACU length of stay is 51 minutes shorter at MGWest. The parameter was coded as MGH equal to 0 and MGWest equal to 1. When surgical site is MGWest, the estimate value is included and decreases predicted PACU length of stay by 51 minutes. Case length was the second most significant factor. Longer surgeries require more anesthesia, which leads to longer recovery times. Other significant factors included subsets of ICD-9 procedure types and surgeons. These two groups are related as orthopedic surgeons specialize and only perform certain orthopedic procedures.

Table 2: Summary of most significant factor estimates

Factor	Method	Estimate	t Ratio	Prob > _t_
Surgical Site	AIC	-51.75	-37.48	<.0001
	K-Fold	-51.12	-37.52	<.0001
Case Length	AIC	0.23	13.09	<.0001
	K-Fold	0.22	12.78	<.0001

The results from the regression analysis demonstrate that surgical site does indeed play a significant role in a patient's PACU length of stay. The model predicts that the same procedure performed by the same surgeon on the same patient would result in a 51-minute shorter PACU length of stay if performed at MGWest. The actual time spend in surgery is the same at both sites, while the post-operative, PACU length of stay varies by almost an hour. The relationship between case length and PACU length of stay from the regression model is logical, as each minute spent in surgery leads to approximately 15 seconds of PACU recovery time.

2.4 Discussion

We began the analysis of PACU operations by first characterizing the current state. As noted previously, this was the current state in 2010 through August of 2011, before the opening of the Lunder building. A basic understanding of patient flow on the day of surgery was the first step. In order to identify opportunities, we compared MGH data to the internal benchmark of MGWest. The first cut was to look at post-operative or PACU length of stay data for the same surgeon performing the same surgical procedure at the two sites. After finding what appeared to be a difference in post-operative length of stay performance, a linear regression model was developed to validate these assumptions and determine the time contribution of surgical site to post-operative length of stay.

The regression model incorporated all possible contributing factors and found that the surgical site was indeed the most significant variable. This confirmed our earlier assumption that even though the surgical procedures and times were the same across sites, operational differences in PACU operations

[17] Significance is determined by absolute magnitude of the t ratio.

were driving significant variances in PACU length of stay between MGH and MGWest. In conclusion, the post-operative, PACU length of stay experienced at MGWest is approximately 50 minutes shorter than at MGH. This motivated us to explore the differences in clinical and operational processes between MGH and MGWest through a root cause analysis. The study comparing these two sites was performed in September 2011, after the opening of the Lunder building at MGH. The patient flow with regards to outpatients became more disjointed (as a two-step process was incorporated) and all PACUs were now housed both inpatients and outpatients. The statistical analysis and linear regression was base on data from the one-stop, dedicated outpatient PACU configuration.

Chapter 3: Root Cause Analysis

3.1 Introduction

The data analysis discussed in chapter 2, suggests that there exists a significant opportunity to reduce average PACU length of stay at MGH. The next stage is to identify the sources of additional time spent processing patients at MGH. For this we employ a comparative observational time study performed at MGH and MGWest to track patients through the PACU process and determine which steps are driving longer lengths of stay at MGH[18]. This study was performed in September 2011 after the August 2011 transformation of the MGH PACU system.

3.2 Methods

Mapping the process at each location and performing an observational time study provides several benefits. First, we are able to capture more granular time stamps than those tracked currently. The patient tracking systems employed at MGH and MGWest only record the time when a patient enters and exits the PACU. Performing an observational time study allows us to break down the length of stay in the PACU into discrete steps and measure which steps are the greatest drivers of PACU length of stay. Table 3 summarizes these steps.

Table 3: Steps in the PACU recovery process

Step	Description
1	Surgery complete (the time when the surgery concludes)
2	Patient arrives at PACU
3	Anesthesia report is complete (anesthesiologist finishes report to PACU nurse and exits the PACU)
4	Patient meets clinical discharge criteria and is removed from vital sign monitor
5	Discharge teaching is complete (Nurses perform discharge teaching, which involves going over medications, precautions, exercises or any other instructions from the surgeon)
6	Patient exits PACU

First-hand observations also provide qualitative benefits that cannot be derived from data analysis. Interaction with the front line workers provides opportunities for idea generation and solution brainstorming. In addition, having a third party observer perform the study at both locations allows for consistent and unbiased data collection. The downside of this type of study is that it is quite time

[18] The method of observational time study has been employed at other institutions to investigate PACU length of stay. See (Waddle, Evers, & Piccirillo, 1998).

Table 4: Average time and standard deviation for each PACU process step

Summary Data from Observational Time Study	Average		Standard Deviation	
Process Step	MGH	MGWest	MGH	MGWest
Surgery Complete to arrival	0:25	0:07	0.020	0.002
Arrival to end of report	0:09	0:02	0.002	0.001
End of report to met criteria	1:07	0:39	0.038	0.019
Met criteria to end of discharge teaching	1:30	0:34	0.022	0.010
End of teaching to departure	0:18	0:09	0.014	0.006
Total Time from Surgery complete to Discharge	**3:31**	**1:34**	0.052	0.027

In addition, there was far more variability in the process times observed at MGH than those at MGWest. The standard deviation of the times observed at MGH was twice that of MGWest. The process in place at MGH results in longer times with greater variability.

The time intervals in the process with the largest differences between surgical sites were the time from the "end of report to met criteria" (green bar in Figure 6) and the time from "met criteria to end of discharge teaching" (purple bar in Figure 6). These process steps also had the greatest observed standard deviations among all of the process steps. The root cause analysis focuses on these process steps, as they provide the greatest opportunity for improvement. We will separately investigate the root cause of delays before and after the "patient meets clinical discharge criteria."

3.3.1 Root Cause of Delays prior to the patient meeting discharge criteria: Mixed Population PACUs

On average, the patients observed at MGWest were deemed to have met criteria 28 minutes sooner than those at MGH. Once again, we are using comparable patient populations and procedures that could have had surgery at either site. Based on staff interviews and observations during the time study, the primary cause for this difference is believed to be nurse availability.

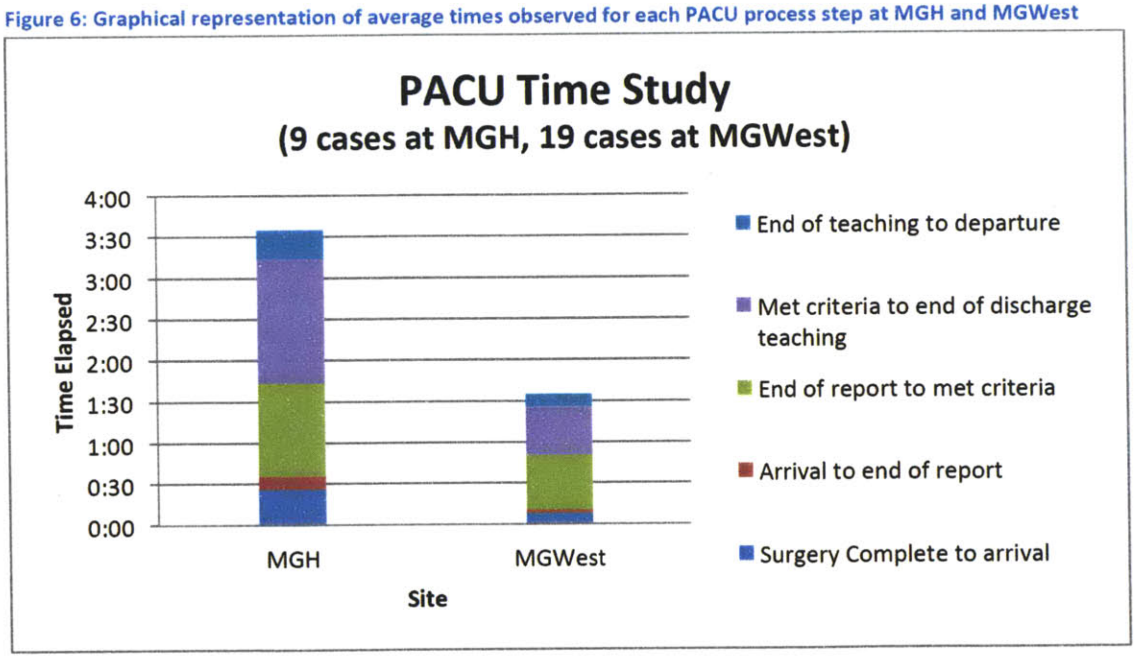
All cases observed at MGWest received one-on-one nurse to patient care. Also, MGWest only cares for outpatients so the population in the PACU does not contain inpatients. These patients had the undivided attention of the assigned nurse. In contrast, at MGH, a nurse was assigned to two patients. Not only was his or her time divided between two patients, but often the other patient was a complex inpatient recovery and not a straightforward, outpatient wake-up. In general, outpatients require less attention than inpatients as they are in a less critical state. The result is that PACU nurses assigned to one inpatient and one outpatient often spent the majority of their time with the inpatient, while occasionally checking in on the outpatient.

While outpatients at MGWest were identified as having met criteria in real-time, there was often a delay at MGH due to the shared nurse resource in a mixed population PACU. By no means are the nurses neglecting the outpatients at MGH, but when faced with caring for two distinctly different patients, the nurses have no choice but to dedicate more time to the more critical patient. Another undesirable effect of having mixed population PACUs was that anesthesia signoff was required for all discharges. At consuming, which leads to a limited sample size. A total of 9 cases at MGH and 19 at MGWest were observed with time stamps taken at each step of the recovery process. The goal of the study was to determine potential areas for improvement based on the limited data set. The observations and conclusions from this time study should not be interpreted as statistically significant.

3.3 Results

On average, every step in the process took longer at MGH than at MGWest and with greater variability. Table 4 displays the average time it took to complete each step of the PACU recovery process at MGH and MGWest. The total time from surgery completion until PACU discharge was almost 2 hours longer at MGH. While some of the discrepancies can be attributed to the physical size difference between the two facilities, the majority of the time difference is due to operational differences. It is important to note that this study was performed after the opening of the Lunder building in August 2011. The new process flow for outpatients at MGH increased their lengths of stay in the PACU. This contributes to the much larger gap observed in this limited study, 1 hour and 57 minutes, as compared with the 50 minute difference indicated by the linear regression of data prior to the Lunder opening.

Figure 6: Graphical representation of average times observed for each PACU process step at MGH and MGWest



*Study performed in September 2011

MGWest, nurses could deem a patient clinically ready when he or she met the American Society of PeriAnesthesia Nurses (ASPAN) standards for PACU discharge. Since the PACUs at MGH have both inpatients and outpatients, the policy is to have all patient discharges approved by anesthesia to avoid confusion. Previously, when the MGH patient populations were segregated (inpatients and outpatients), nurses could discharge outpatients when they met clinical criteria. This could be done without anesthesia intervention.

Through a simple "five why" analysis,[19] one can determine that the root cause of the delays prior to meeting discharge criteria is the use of a mixed population PACU, namely one with both inpatients and outpatients. Having an area dedicated for outpatient recoveries would allow nurses to more closely monitor the progress of outpatients. This would reduce the time spent waiting for a nurse to progress the patient to the next step in recovery and shorten overall PACU length of stay.

3.3.2 Root Cause of Delays after meeting discharge criteria: Two-step recovery process

One interesting result from the observational study was that the greatest difference in processing times between the two sites occurred *after* the patient met clinical discharge criteria. The average time to perform this step was 56 minutes longer at MGH than at MGWest. One would expect that discharge process to be a quick administrative checkout from the PACU. This step consists of discharge teaching in which the nurse walks the patient through the instructions left by the surgeon. These usually include a prescribed medication overview, tips for sleeping, and basic exercises to perform.

At MGWest, once the patient met clinical discharge criteria, the nurse would have the patient sit up, have something to eat, then get the patient escort and begin the discharge teaching. This lasted 34 minutes on average with about 20 minutes spent on actual teaching.

The process is quite different at MGH where a two–step recovery process for outpatients requires a handoff to a second PACU nurse in a second recovery location. This two-step process was instituted when the PACUs were reconfigured with the opening of the Lunder building in August 2011 (see 2.1.3 for a description of the PACUs before and after the new building). This two-step process caused many delays in the processing of outpatients. Additional time stamps were recorded at MGH to understand what comprised the 56 minutes of additional time. Table 5 summarizes the average times in each sub step experienced by patients at MGH. It is important to note that a patient still occupies a PACU slot and a nurse while waiting for the escort to arrive. The patients continue to be monitored in the PACU; they are not sent to a separate waiting area. The scarce resources are the PACU slots and the nurses

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[19] "Five Whys" is a LEAN technique popularized by Taiichi Ohno of Toyota. It involves asking why five times when a problem is encountered to identify the root cause of the problem. Only after identifying the root cause can effective countermeasures be developed and implemented (Womack & Jones, 2003).

assigned to those slots. A slot is "closed" when it is not staffed with a nurse. Therefore, shorter patient stays in the PACU will free up nurses and the corresponding PACU slots.

Table 5: Breakdown of time spent between meeting discharge criteria and the end of discharge teaching at MGH

	MGH	MGWest
Met Criteria to end of discharge teaching	**1:30**	**0:34**
Time from meeting criteria to depart for Wang	0:33	
Travel time to Wang	0:03	
Arrival in Wang to end of discharge teaching	0:54	

The average time from when a patient met criteria until the end of discharge teaching was 90 minutes at MGH, as compared to 34 minutes at MGWest. The first 33 minutes were spent waiting in one of the phase 1 PACUs before leaving for the phase 2 PACU (CPC). The travel time of 3 minutes was consistent and no major delays were observed during any of the patient transportations. Once arriving in the phase 2 PACU the average time until the end of discharge teaching was 54 minutes. Next, we will look at each sub step in the process at MGH.

The 33 minutes from when the patient meets criteria until he or she departs from the phase 1 PACU consists of the following steps:

1) After patient has met clinical discharge criteria a bed is requested in the phase 2 PACU
2) Phase 1 nurse waits until a bed is assigned in the phase 2 PACU
3) Phase 1 nurse calls and gives report to the phase 2 nurse
4) Transport is requested
5) Transport team arrives and leaves with the patient

The patient is still being cared for during these 33 minutes, but he or she is simply waiting rather than progressing towards discharge. This time spent waiting is pure waste or *muda* in LEAN terminology (Womack & Jones, 2003). Womack defines *muda* as any activity that consumes resources but creates no value, otherwise known as non-value added activity. The nurse cannot take another patient, and the bed is still occupied (i.e., resources are being consumed), but the patient has not been processed any further. There are even additional delays within each step. For instance, often nurses call each other several times before both of them have the time to give and receive the report over the phone.

Incorporating a one-step recovery process for outpatients would eliminate these 33 minutes of non-value added time and allow nurses to proceed to discharge teaching almost immediately after the patient met discharge criteria.

The 54 minutes from when a patient arrives in the Phase 2 PACU until the end of discharge teaching are spent getting the patient comfortable in a new setting and going over the discharge teaching. When a patient arrives in the phase 2 PACU, he or she is moved from the bed into a recliner. The patient still occupies the PACU slot and associated nurse resources when he or she is in the recliner. The nurse asks a series of questions to assess the patient and then goes on to discharge teaching. The teaching observed at MGH was often interrupted because the nurses were caring for multiple patients. The time a patient spent waiting for a nurse is another form of *muda*.

Several other outpatient-specific best practices were observed at MGWest. As stated previously, nurses can deem an outpatient clinically ready for discharge based on meeting the clinical discharge criteria also known as the ASPAN standards[20]. At MGH, anesthesia signoff is required[21]. Outpatients at MGWest sat upright in recliners as soon as they met clinical discharge criteria and could be removed from the vital sign monitors. In contrast, at MGH, the patients did not sit upright until they arrived in the phase 2 PACU. Another difference in practices was that MGWest brought patient escorts into the PACU *before* teaching. This was not the common practice at MGH, which resulted in some repeating of the instructions when the escort was present. These benefits of an outpatient dedicated PACU are not realized at MGH due to the mixed population PACUs and two-step recovery process. Since the new two-step process at MGH had just been implemented in August 2011, these observations, conducted in September 2011, were the first that compared the new MGH process with that of MGWest.

3.4 Discussion

The observational time study performed at MGH and MGWest identified two major sources of delay and the root cause for each. First, the time until a patient meets discharge criteria was 28 minutes longer at MGH. This is attributed to having mixed population PACUs. In PACUs with inpatients and outpatients nurses are often less available to outpatients which leads to delays in processing towards clinical readiness. Second, the time from when a patient meets criteria until the end of discharge teaching was 56 minutes longer at MGH. This is due to the two-step process at MGH that involves a PACU Nurse-to-PACU Nurse handoff and transporting the patient to a second recovery location. A one-stop recovery allows the PACU nurse to perform some steps in parallel thus shortening the overall PACU length of stay. Our proposed solution seeks to address both root causes of delay by having a one-stop/one-nurse recovery process within a designated outpatient PACU location.

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[20] ASPAN *Standards of PeriAnesthesia Nursing Practice* provides a framework for the care provided to patients across all perianesthesia settings (American Society of PeriAnesthesia Nurses, 2011).

[21] This was instituted at MGH when the outpatient and inpatient populations were mixed because all inpatients require anesthesia signoff. In order to avoid confusion, the policy was instituted that all patients in the mixed PACUs required anesthesia signoff.

Chapter 4: Design of Proposed Solution

4.1 Introduction

Having identified root causes of delays in the system through the observational time study, we are now prepared to develop a new system that addresses these sources of delay to reduce PACU lengths of stay. Recall that the goal is to increase capacity without adding resources. By reducing the average PACU length of stay, the PACU throughput increases with the same resources, thus increasing our operational capacity. Our solution must have two key characteristics:

1) An area designated only for outpatients
2) A one-step recovery process in which patients visit a single PACU and have one PACU nurse

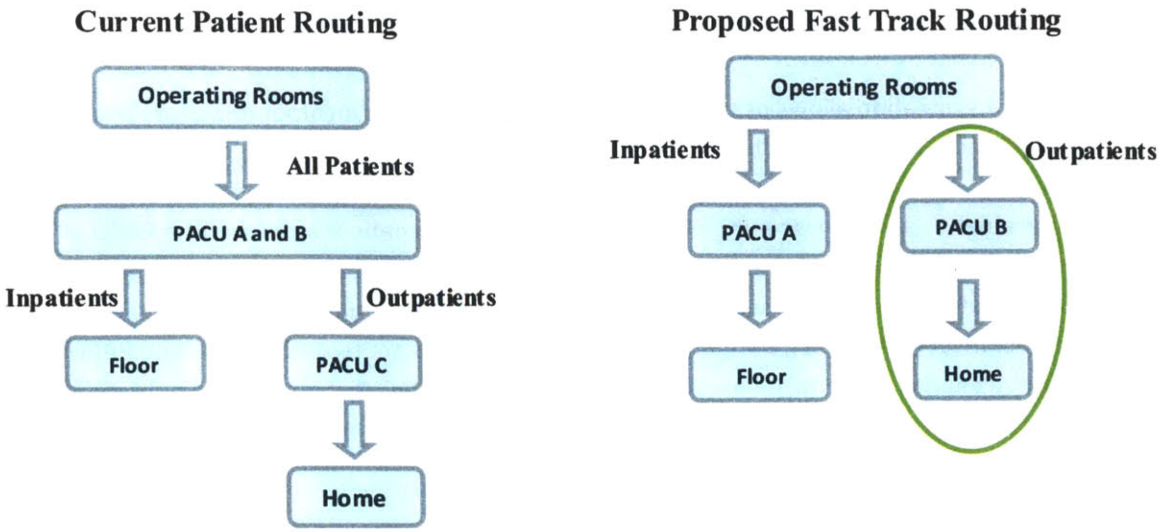
Our solution focuses on reducing outpatient PACU length of stay, as these patients are not gated by the downstream bottleneck posed by the congestion of the inpatient beds. Lessons learned in reducing outpatient PACU time can be transferred to the inpatient population, but true gains for inpatients will not be realized until the downstream inpatient beds are no longer a bottleneck in the system. We will not be able to completely duplicate the PACU process at MGWest due to differences in the patient populations and constraints on MGH staffing levels, but by incorporating most of the outpatient best practices, we can achieve substantial savings. We assume that we can achieve a 50% improvement toward the MGWest benchmark by incorporating a designated outpatient area or Fast Track.

Establishing this Fast Track will also allow MGH to pursue other avenues of continuous improvement, which are not possible in the current environment. Essentially, MGH will be able to further optimize the outpatient flow system design and incorporate outpatient-specific best practices once this population is routed to a dedicated area. The first step is constructing an outpatient Fast Track solution that eliminates the systematic sources of delay.

4.2 Description of the Outpatient "Fast Track" Solution

The proposed solution depicted on the right in Figure 7 segregates the two patient populations upon exiting the operating room. All outpatients are routed to a single PACU for a one-stop recovery. Outpatients are no longer routed to the secondary PACU location (PACU C in Figure 7). The nurses currently assigned to recoveries in this location can be deployed to the primary recovery locations to increase operational capacity. These additional resources are needed now that the entire outpatient length of stay will occur at a single location. The number of beds dedicated to outpatients can be flexed up or down depending on daily or hourly outpatient demand. By separating the inpatient and outpatient populations, the PACU operations in each location can be specialized to cater to the needs of each patient type. This solution addresses both the mixed population and two-step recovery issues identified in the current system.

Figure 7: Current Patient Routing vs. Proposed Fast Track Routing



By designating an area for outpatient recoveries, we can further build a culture and workflow focused on high throughput patients. Lessons learned from MGWest can be incorporated into the Fast Track that cannot be implemented in the current mixed population environment. Practices such as clearing patients for discharge based on meeting clinical criteria without signoff by anesthesia, sitting the patient upright when clinical discharge criteria has been met, and having patient escorts present for discharge teaching can all be implemented in the Outpatient "Fast Track".

4.3 Operational Concerns with Proposed Solution

Now that we have a proposed solution that addresses the root causes of delays, we must determine if it is feasible in the current environment and address the operational issues and concerns that arise with this new process recommendation. The primary question is whether we have the physical capacity to implement such a solution. The PACUs process not only patients who are recovering from surgery, but also some patients that are preparing to have surgery (preoperative patients). Another concern is that routing patients based on patient type may cause one PACU to become overcrowded and cause increased PACU delays.

To address these questions, we turn to discrete event simulation modeling. By simulating patient arrivals as they actually occurred in November 2011, we can evaluate how the proposed solution would have performed under these conditions. We can determine if sufficient physical capacity exists and if staff assignments should be altered to accommodate the new demand profile that results from the Fast Track routing logic. In addition, we would like to predict the quantitative benefits of the proposed solution. The simulation will allow us to estimate the potential reduction in average outpatient length of stay with the proposed solution.

Chapter 5: Simulation Results

5.1 Introduction: Developing a Discrete Event Simulation Model

Discrete event simulation allows us to test what would happen if we incorporated "Fast Track" routing. We use the MedModel simulation software, a package offered by ProModel[22]. The model contains all of the PACU locations, each with its assigned physical capacity. Patient arrivals in the model are based on actual arrival times that occurred in November 2011. For example, if a patient arrived at the PACU at 8:52 am on November 15th, 2011 then in the model a simulated patient arrives at the PACU at this same exact time. Patients are routed to a PACU based on the routing scenario. In the baseline scenario, each patient follows his or her historical routing (i.e., both inpatients and outpatients are routed to the same PACUs). In the "Fast Track" scenarios, patients follow the "Fast Track" routing logic (inpatients and outpatients are routed to separate PACUs). The baseline scenario allows us to validate the model against actuals before testing the feasibility of "Fast Track" routing.

5.2 Methods

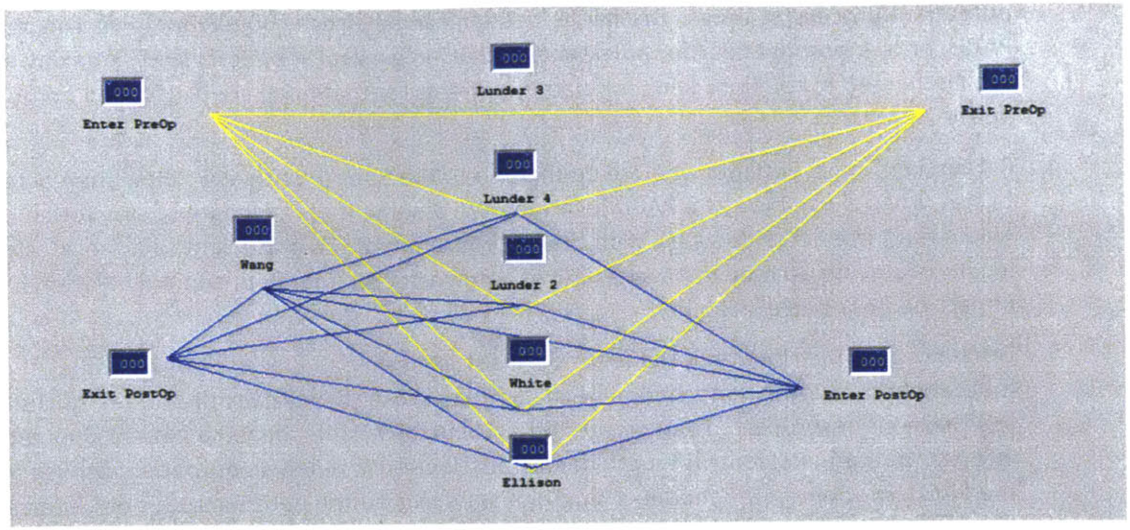
5.2.1 Model Elements

1. Locations: The locations included in the model are the five perioperative locations that can function as phase 1 PACUs (White 3, Ellison 3, Lunder 2, Lunder 3, Lunder 4) and the phase 2 PACU (Center for Perioperative Care, previously Wang 3). Each PACU has a capacity equal to the physical number of slots in that PACU. A PACU slot in the model represents a staffed slot[23]. Below is a screenshot of the model location layout with the preoperative patient flow (in yellow) and postoperative patient flow (in blue). Preoperative patients were modeled because they share resources and capacity with PACU patients in some PACUS.

[22] ProModel is a leading business process optimization and decision support company serving the pharmaceutical, healthcare and manufacturing industries (ProModel, 2012)

[23] The number of staffed PACU slots determines if a patient can enter the PACU. Nurse resources were not incorporated separately into the model. This was considered, but rather than have current staffing patterns determine feasibility, we chose to have the model output drive staffing patterns. See appendix 6.3 for PACU delays (service level) for different peak staffing levels by two-hour time intervals.

Figure 8: Simulation Model Locations with Preoperative and Postoperative Patient Flows



2. Entities: The entities being processed in the model are patients. Different patient types are incorporated to reflect the different patient categories. The length of stay distribution followed by a particular patient is determined based on this patient category. These include Ambulatory Surgery (AS), Inpatients (IN), Same Day Admits (SD), Routine Post Procedure Recoveries & Observations (RROB), PACU Overnighters, and electroconvulsive therapy (ECT) Patients (non-surgical patients that occupy PACU slots). In addition, the patients are identified as pediatric or adults as this also influences PACU length of stay. Therefore, the entities in the model include:

    - Adult_AS
    - Adult_IN
    - Adult_SD
    - Adult_RROB
    - PEDI_AS
    - PEDI_IN
    - PEDI_SD
    - PEDI_RROB
    - ECT
    - PACU_Overnighter

3. Arrivals: Patient arrivals in the model are based on historical arrival times from November of 2011. An arrival file is fed into the model that contains the actual arrival time of each patient entering the PACU. In addition to the time of arrival, the arrival file indicates the patient type, the location it arrives to, the patient's discharge location, and the actual length of stay that was

experienced by the patient. The actual lengths of stay are used in validation and also for non-outpatient processing times. Discharge location can be directly home, home via the phase 2 PACU, or to a hospital floor for an extended stay. In general, inpatients and same day admits are discharged to the floor and ambulatory patients (outpatients) are discharged home via the phase 2 PACU[24].

4. Processing Times: Patients who are discharged to the floor (inpatients) follow their actual length of stay when they arrive at a PACU location. We assume that the length of stay for an inpatient would not increase or decrease with the incorporation of the outpatient Fast Track. Inpatient length of stay is gated by the availability of a downstream floor bed, and our solution has no impact on floor bed availability.
5. Length of Stay Distributions: The focus of this study is on patients discharged home (outpatients), but inpatients had to be included because they occupy the same PACU slots (i.e., use the same resources). To minimize the noise in the system, only the patient population of interest, outpatients, follows length of stay distributions. When an outpatient arrives to one of the PACU locations in the model, a length of stay distribution determines his or her processing time at that location. These distributions are explained in more detail in the following section.

5.2.2 Length of Stay Distributions

The most recent data set of PACU patient records from November 2011 is used to fit distributions for patient length of stay in the model, as it is the most accurate representation of current performance. As mentioned previously (see section 2.1.3), average PACU length of stay increased dramatically with the opening of the new Lunder building in August of 2011. Reconfiguring of the PACUs initiated a period of adjustment and learning by PACU nurses. Improvements in PACU length of stay performance were experienced in the fall of 2011 and a new operating room schedule was implemented on October 31st 2011. Due to these recent changes, data from November 2011 was used to build current performance distributions used in the simulated baseline scenario.

When running "Fast Track" model scenarios, two different distributions were used to predict outpatient length of stay performance[25]. One was based on the PACU length of stay data from the previous one-stop outpatient recovery PACU at MGH that was in use prior to the opening of the Lunder building (Wang 3 PACU July 2011). This PACU primarily performed outpatient recoveries and discharged patients directly home. The most current and complete data from this PACU is from July 2011. This is the data used to construct the outpatient length of stay distribution in the "Fast Track Wang July 2011" scenario. The second distribution was based on a 50/50 mix of the Wang July 2011 distribution and a distribution constructed using MGWest

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[24] Discharge location for RROB patients is mixed between home and floor.

[25] Non-outpatients do not follow a distribution. These patients stay for their actual length of stay from the November 2011 data.

PACU performance from July-September 2011[26]. Outpatients in the "Fast Track 50% Wang July 2011 50% MGWest" scenario follow a length of stay distribution that combines both distributions each with a weight of 0.5. By incorporating lessons learned from MGWest and having an area focused on high throughput recoveries, we expect to achieve half the performance of MGWest[27]. Table 7 summarizes the different scenarios and table 8 provides the expression for each distribution that was fit to historical length of stay data.

Table 6: Summary of Model Scenarios

Scenario	Routing Logic	Outpatient Length of Stay (LOS) Distribution
Actuals	Historical	No distributions used. Outpatients stay in the PACU for his or her **actual** LOS from November 2011 data.
Simulated Baseline	Historical	Outpatients follow **distribution** of November 2011 actual LOS data.
"Fast Track" Wang July 2011	"Fast Track"	Outpatients follow distribution of Wang Actuals from July 2011.
"Fast Track" 50% Wang July 2011 50% MGWest	"Fast Track"	Outpatients follow mix of Wang July 2011 and MGWest July-Sept 2011 distributions.

Table 7: Length of stay distributions

	Outpatient Length of Stay Distributions	Data Set
MGH_Floor	32+165*(1/((1/U(0.5,0.5))-1))**(1/2.08)	November, 2011
MGH_Home	29+108*(1/((1/U(0.5,0.5))-1))**(1/2.34)	November, 2011
MGH_Home via CPC (phase 1)	25.+G(2.69, 32.4)	November, 2011
MGH_CPC (phase 2)	47.6*(1/((1/U(0.5,0.5))-1))**(1/3.23)	November, 2011
MGWest_Home	20.+ER(77.5, 4)	July to September 2011
MGH_Wang July 2011	-55.8+L(203, 73.2)	July, 2011

5.2.3 Model Assumptions

Several simplifying assumptions are necessary in the development of the discrete event PACU simulation.

1) Patient mix and PACU times from November 2011 represented a typical month at MGH. Specifically, the output of the model demonstrates what would have happened had these different scenarios been in place

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26 Since practices at MGWest had not changed recently, we were able to use three months of data to a build length of stay distribution for MGWest PACU patients.

27 We cannot assume we can fully achieve the MGWest performance due to the physical size and increased complexity factors inherent to MGH. Achieving 50% of MGWest performance was deemed attainable and may even be a conservative estimate on expected improvement.

in November of 2011. This was the most recent data available and reflects patient mix after the new operating room schedule was instituted. In order to run the model for a greater data set, a new arrival file with historical arrival times can be fed into the model. In addition, arrival time and patient mix distributions could be developed and input into the model to generalize the demand profile of the MGH PACUs. We chose to use historical data, as this was the most accurate representation of the mix and volume of PACU arrivals.

2) Phase 1 recovery occurs entirely in the first phase 1 PACU a patient visits. In reality, patients are sometimes transferred among the phase 1 PACUs, specifically, at the end of the day when patients are moved to the 24-hour phase 1 PACU (Ellison 3). These transfers are not modeled due to the difficulty in capturing these transfer times. Transfers from a phase 1 to the phase 2 PACU are modeled, as this is part of the discharge process. Since our goal is to analyze the effect on total PACU length of stay, these inter-PACU transfers are not significant for our purposes.

3) PACU location capacities reflect physical number of staffed PACU slots. An open PACU slot in the model reflects a physical slot with a nurse assigned to it. The intent is for the output of the model to drive staffing patterns, rather than staffing patterns altering the output of the model. All scenarios were run both with and without the physical capacities enabled. We choose to focus on the scenarios without capacities when performing our analysis. This allows us to document when physical PACU slot capacity is reached and by how far we would exceed capacity. The scenarios with physical capacities enabled were used to generate expected PACU delay events (delays entering the PACU) for different staffing levels.

4) Patient length of stay is not a function of current PACU utilization. Each outpatient's PACU length of stay is randomly selected from the length of stay distribution. This does not take into account current PACU utilization level. In reality, these lengths of stay are not entirely independent, which causes more extreme peaks and valleys in occupancy levels. Changes in simulated occupancy levels are more gradual in nature.

5.2.4 Model Validation

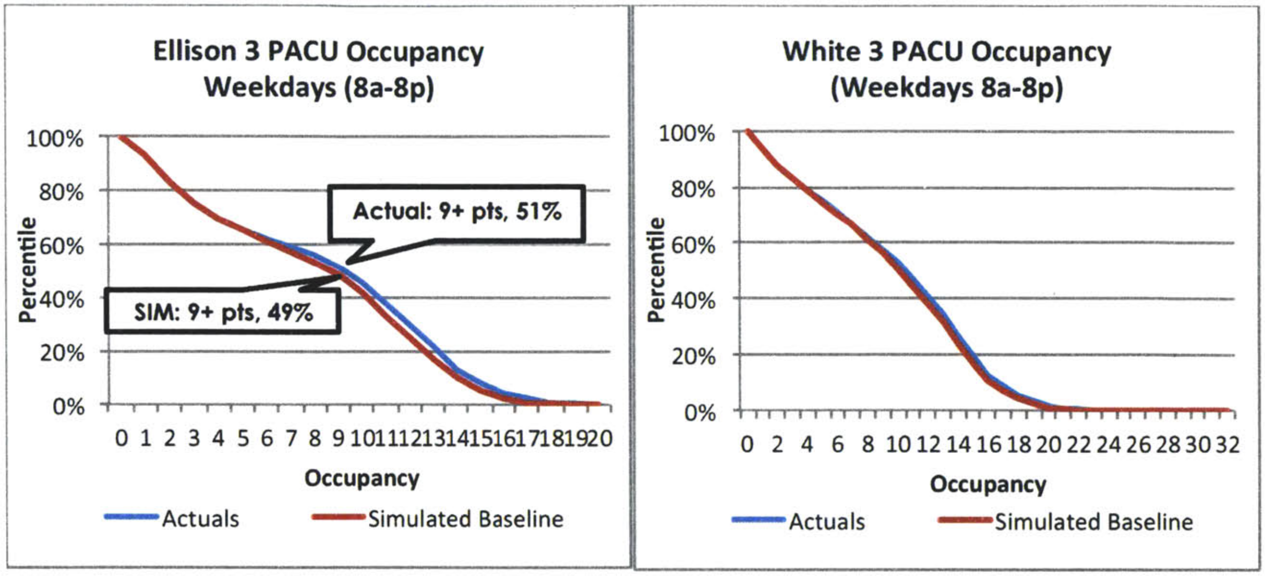
To validate the model, we compare the occupancy distributions for the baseline scenario against the actuals from November 2011.

Simulated patient arrivals occur as actual arrivals occurred in November 2011, and all non-outpatients stay in the PACU for the amount of time they spent in the PACU in reality. Therefore, any variability between the actuals and simulated baseline is attributed to the outpatient length of stay distribution used in the simulation. While the exact occupancies should not match up due to the randomness associated with using a distribution, we should see roughly the same occupancy frequencies.

Figure 9 displays the actual and simulated baseline occupancy frequencies for the two primary phase 1 PACUs (Ellison 3 and White 3). As an example, in Ellison 3 actuals from November 2011 indicate an occupancy level of nine or more patients 51% of the time, as opposed to 49% of the time in our simulated baseline. These graphs display occupancy frequencies for the operational day of 8am to 8pm. This same analysis was performed for every two-hour time interval between 8am to 8pm (see appendix for output graphs). In all instances, simulated baseline occupancies track very closely, within one patient, of actual occupancies.

The simulated baseline generates a good approximation of actual occupancies experienced in November of 2011. Next, we use the simulation to test the Fast Track scenario to explore if and under what operational conditions it could be implemented, as well as the resulting performance.

Figure 9: Actual Occupancy Frequencies vs. Simulated



5.3 Results

The simulation experiments aim to answer two major questions:

1) What is the expected benefit of implementing the outpatient "Fast Track"?
2) Do we have the physical infrastructure (i.e., number of beds in each PACU) to accommodate the expected patient volumes in each PACU?

5.3.1 Benefits of a Implementing an Outpatient "Fast Track"

The proposed outpatient "Fast Track" will not only address two of the main sources of delay in the outpatient recovery process, it will also lay the groundwork for future improvement. Once a PACU location is designated for outpatients, outpatient-specific best practices can be incorporated and further continuous improvement projects can be initiated. The current environment impedes outpatient-specific process improvement. We believe MGH can achieve significant length of stay reductions and can close the gap with MGWest performance by at least 50%. The proposed solution addresses system design aspects that are the primary sources of delays today, as well as establishing an environment conducive to further continuous improvement. Further benchmarking of MGWest should be performed once the "Fast Track" is implemented to identify opportunities for additional improvement.

This initial outpatient "Fast Track" recommendation is designed to eliminate two of the main causes of delay in outpatient recoveries: mixed population PACUs (inpatient and outpatients) and the two-step, two-location recovery process for outpatients. While the qualitative benefits of having a single nurse care for a patient throughout the entire recovery process may be obvious, how this translates to quantitative savings is much less clear. The discrete event simulation predicts performance parameters of the "Fast Track" scenario, thus providing a basis for quantitative savings. Recall that the goal is to increase PACU capacity without adding additional resources. By reducing the average outpatient PACU length of stay, we increase patient throughput and effective PACU capacity. Therefore, the primary metric of interest is average outpatient PACU length of stay.

Figure 10 provides the average outpatient PACU length of stay from each simulated scenario. The simulated baseline scenario is a virtual match to our actual average, which further validates the results of our model. Incorporating a "Fast Track" has a significant impact on outpatient PACU length of stay. The "Fast Track Wang July 2011" scenario represents performance in a single-step recovery process[28]. By returning to a single-step recovery process for outpatients, average PACU length of stay decreases by 22 minutes over November 2011 performance. The "Fast Track 50% Wang July 2011 50% MGWest" scenario represents the added gains that would come from incorporating high throughput recovery best practices from the MGWest surgery center. By further optimizing the outpatient recovery process and incorporating the lessons learned from MGWest, average PACU length of stay decreases an additional 24 minutes for a total reduction from current performance of 46 minutes. That is a 27% reduction in average PACU length of stay, which equates to saving 21.4 hours per day or effectively adding 1.8 additional slots of PACU capacity[29]. This seemingly small increase in capacity has a major impact on patient throughput.

Previous studies performed at MGH have shown that incremental increases in PACU capacity result in substantial reductions in total time patients spend waiting for a PACU bed (Schoenmeyr, et al., 2009). This is a result of high utilization, which is often 95% for several hours a day. Schoenmeyr et al showed that increasing PACU capacity by three beds, about a 10% increase in capacity at the time, resulted in an expected 60% decrease in the total hours patients spent waiting to enter the PACU.

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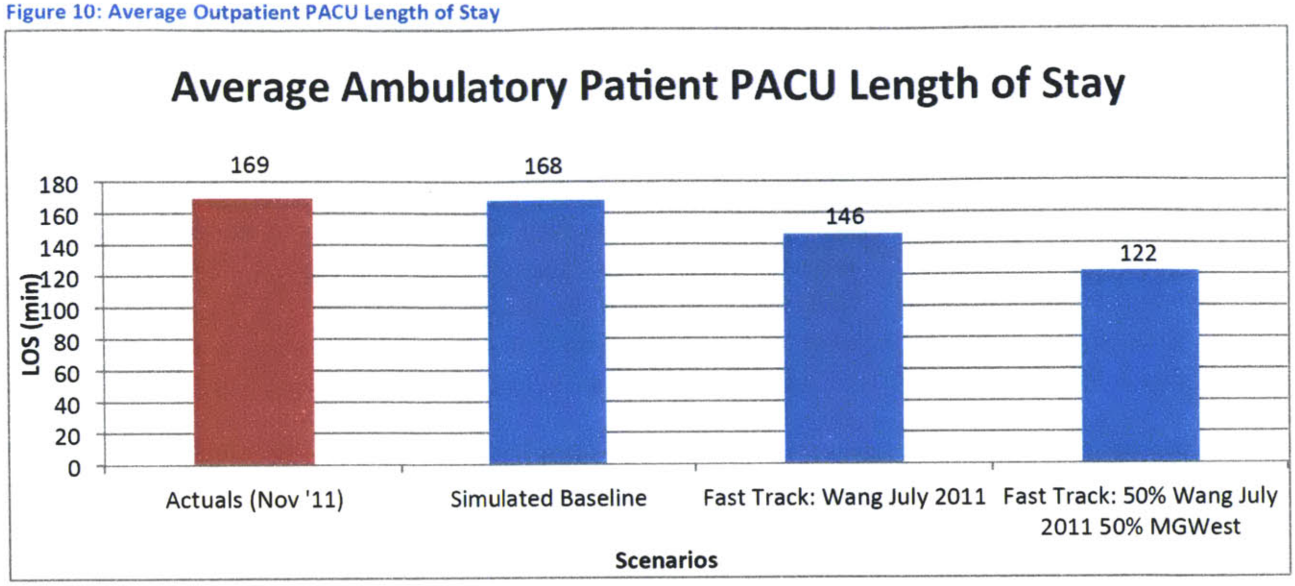
[28] As noted in section 2.a.3 Wang 3 in July 2011 serviced the majority of outpatient recoveries in a one-step process

[29] 559 outpatients recovered in Ellison or White PACUs during the operational day from 8am to 8pm across the 20 standard workdays in November 2011 (excludes holidays and weekends). 559 patients x 46 minutes saved per patient = 25,714 minutes saved or 21.4 hours per day (22,360 minutes / 20 days = 1,286 minutes or 21.4 hours per day). Based on the standard PACU slot being operational for 12 hours (8am-8pm) per day, this equates to 1.8 slots per day saved (21.4 hours / 12 hours per slot per day = 1.8 slots per day).

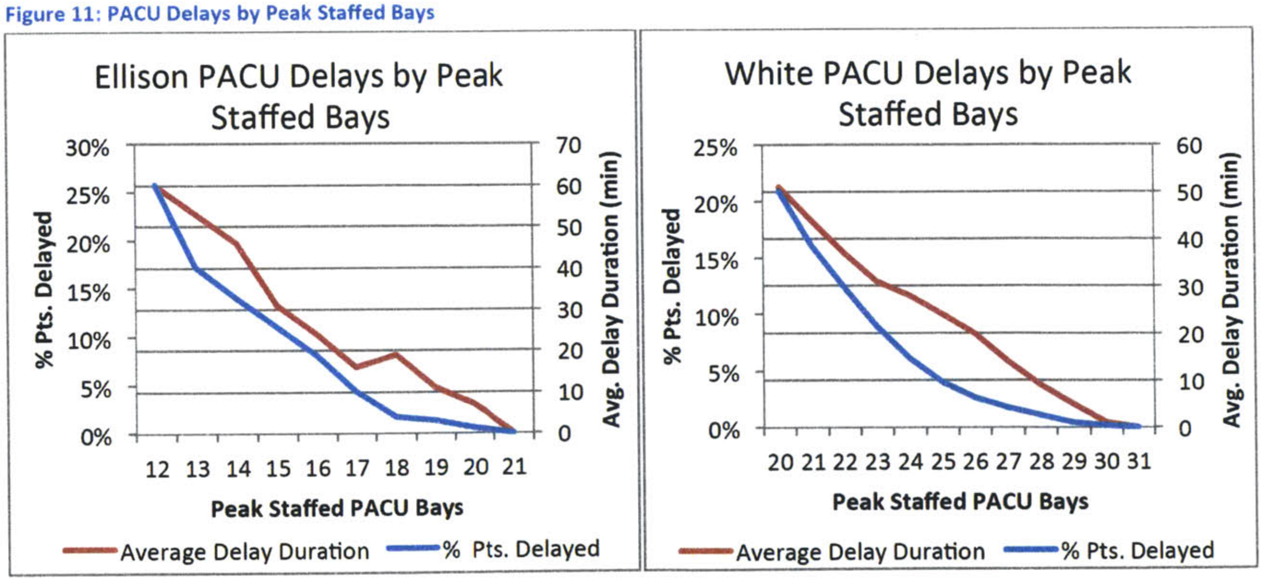
Figure 10: Average Outpatient PACU Length of Stay



*Excludes outpatients in self-contained PACUs (Lunder 2 & 4)

A related benefit is the reduction in PACU delay events. These events are recorded when a patient is ready to leave the operating room, but cannot be received in the PACU due to a lack of an available bed and/or nurse (see section 2.a.2 for detailed explanation of PACU delay events). In November of 2011, 5.8% of surgical cases experienced a PACU delay event and the average duration of delay was 12.5 minutes. Figure 11 displays simulated PACU delays base on different peak staffing levels. Staffing up to the physical capacity of each PACU (20 and 28 for Ellison 3 and White 3 respectively) results in approximately 1% of patients delayed, with average delay duration of 8.5 minutes. See the appendix for PACU delay graphs for each two-hour interval from 8am-8pm.

Figure 11: PACU Delays by Peak Staffed Bays



5.3.2 Feasibility of Implementing an Outpatient "Fast Track"

Now that we have captured the benefits and expected improvement from implementing an outpatient "Fast Track," we focus attention on whether the plan is feasible and what resources it requires. The question is whether it is possible to implement the "Fast Track" within the current physical constraints of the PACUs. Based on the simulated results, we determined that adequate capacity exists to implement the proposed solution. We also study the expected occupancies in the two other PACUs that will be affected by the proposed routing changes. While Ellison 3 PACU is the proposed location for the "Fast Track" the proposed solution also entails routing all of the inpatients to the White 3 PACU[30]. Therefore, we examine both the Ellison 3 and White 3 PACUs to determine expected changes in occupancy levels and proposed staffing levels to accommodate these changes.

5.3.2.1 Ellison 3 PACU Analysis

The Ellison 3 PACU was selected as the location for the outpatient "Fast Track" based on the physical constraints and capacities of the Ellison 3 and White 3 PACUs. In particular, the Ellison 3 PACU has private recovery beds[31], which are required for the pediatric and PACU overnight recoveries[32] (the White 3 PACU does not have private beds and is not suitable for these patients). Since all pediatric and PACU overnight patients must be routed to Ellison 3 PACU only a limited number of beds were available for other recoveries. Since the inpatient occupancy levels far exceed that of the outpatients, Ellison 3 was selected as the preferred location for the outpatient "Fast Track"[33].

The question was whether Ellison 3 has adequate capacity to accommodate all of the outpatients with the pediatric and PACU overnight patients. Our analysis shows that the capacity does indeed exist to route all outpatients to Ellison 3 and recover them in a designated area. We examine simulated occupancy distributions to draw this conclusion. An entire month of PACU patient visits were simulated and the peak

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[30] The Ellison 3 and White 3 PACUs are located adjacent to each other, but have very different physical makeups. The major difference is that Ellison 3 is newer and has all private PACU slots with doors, while White 3 has semi-private slots with curtain dividers between slots. Ellison's physical capacity is 20 operational slots, while White's is 28.

[31] Private recovery slots have closing glass doors while non-private slots are separated by curtains.

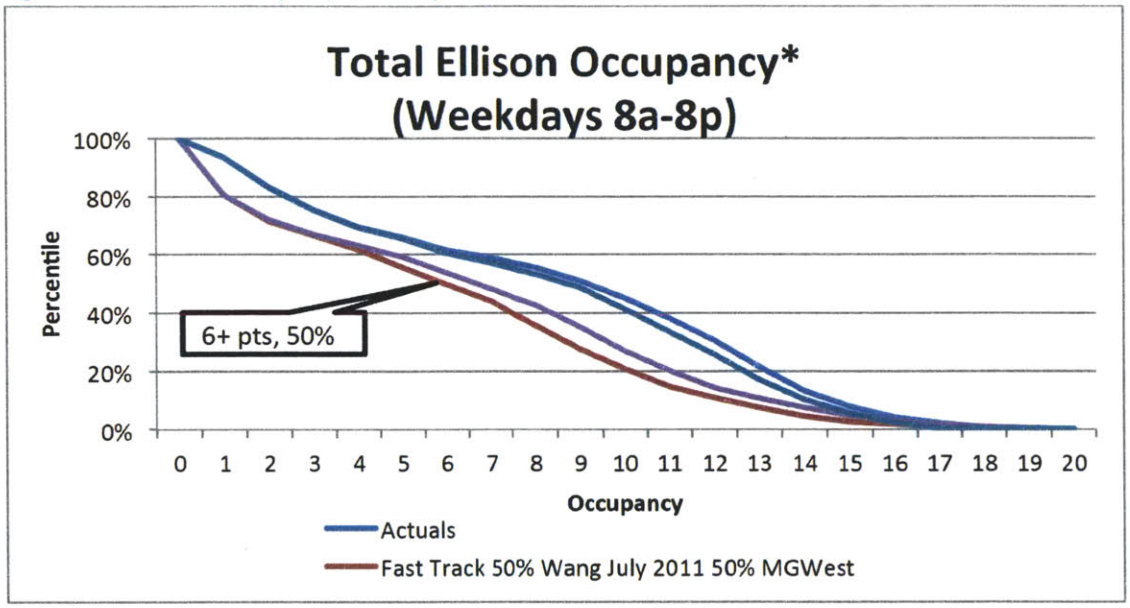
[32] PACU overnight patients are inpatients, which spend the first night after surgery in the PACU. These are expected overnight stays. These are requested prior to surgery and in most cases are the more critical recoveries that require a higher level of monitoring the first night after surgery than is afforded in the hospital inpatient beds.

[33] It is important to note that pediatric and PACU overnight patients require 1:1 nurse to patient care, which means that having outpatients in the same PACU will *not* result in a shared nurse resource simultaneously caring for an outpatient and a pediatric or PACU overnight patient. Nurses caring for outpatients will only be caring for other outpatients, a key construct of our "Fast Track" solution.

occupancies as well as the distribution of different occupancy levels were observed. We choose to analyze the entire distributions, rather than means as this provides a better representation of varying occupancy levels.

On average, incorporating the "Fast Track" in Ellison and routing all inpatients to White decreases the occupancy level in Ellison by 10%. Figure 12Figure 12 displays the occupancy frequencies experienced during weekdays from 8am-8pm (operational day). Ellison 3 PACU experiences low occupancy levels at the beginning and end of the day. Occupancy levels only approach operational capacity in the peak hours (typically in the afternoon). Once again, the percentile associated with each occupancy level is the percent of time that the PACU occupancy achieves at least that occupancy level. For example, the Ellison 3 PACU will have six or more patients 50% of the time in our "Fast Track 50% Wang July 2011 50% MGWest" scenario. Occupancy frequency graphs by two-hour time intervals are included in the Appendix. The important point to note is that we remain comfortably below the Ellison 3 PACU's physical capacity of 20 beds.

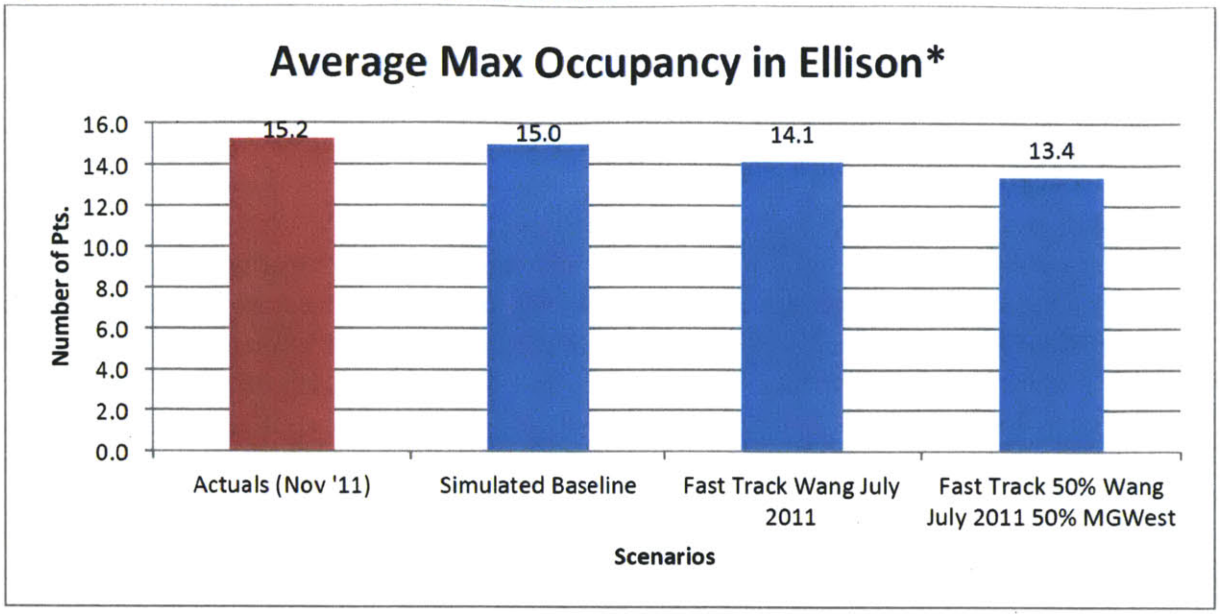
Figure 12: Total Ellison Occupancy Level Frequencies



*Includes pediatric and PACU overnight patient populations

In addition to the overall occupancy frequencies, we are also concerned with the maximum daily occupancy experienced with "Fast Track" routing. We see in Figure 13 that the average daily maximum occupancy (calculated by taking the maximum each day and averaging the maximums) in Ellison reduces by 1.6 patients to 13.4. Ellison 3 is not in jeopardy of becoming over-crowded with the addition of an outpatient "Fast Track". On average, the overall occupancy and daily maximum occupancy both decrease with the proposed solution.

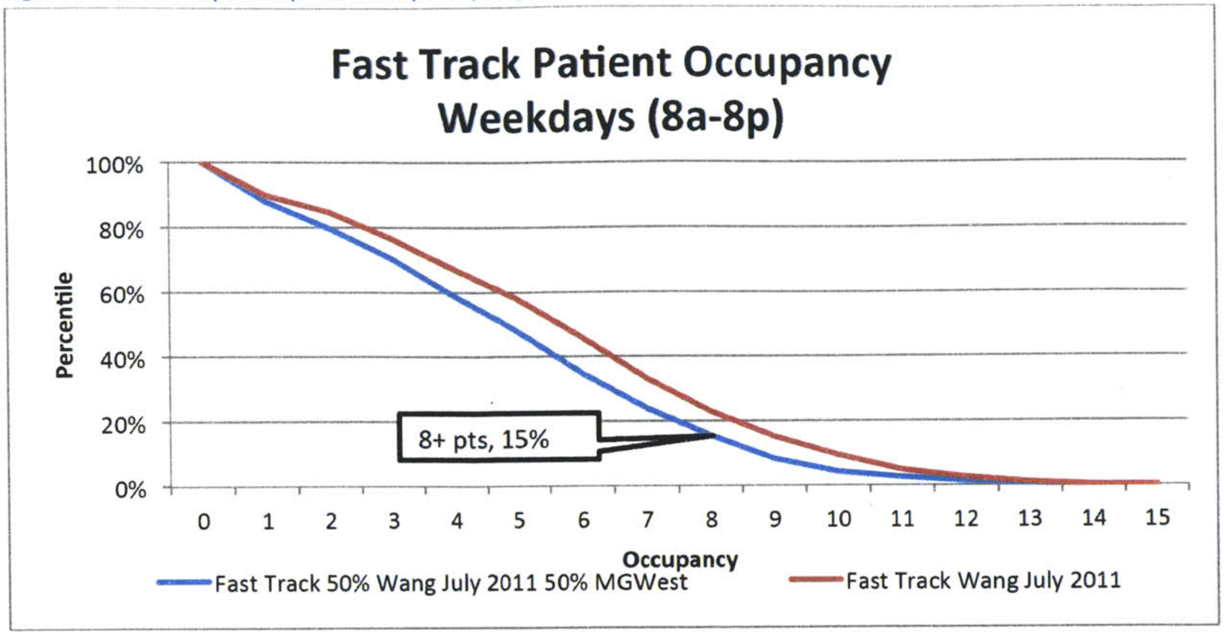
Figure 13: Average Daily Maximum Occupancy in Ellison 3 PACU



*Includes pediatric and PACU overnight patient populations. Physical capacity of Ellison is 20 slots.

In addition to determining if the capacity exists to house the "Fast Track" in Ellison 3, we are also interested in how many beds to designate for the "Fast Track". The discrete event simulation allows us to determine the recommended number of beds to allocate for outpatients. The simulated outpatient "Fast Track" occupancies are shown in Figure 14. We see that there are eight or more patients in the "Fast Track" only 15% of the time. Therefore, the recommendation is to designate eight slots in the Ellison 3 PACU as the outpatient "Fast Track" and flex this number up or down depending on daily demand. These eight slots accommodate the outpatient demand 85% of the time.

Figure 14: Ellison Outpatient ("Fast Track") Occupancy Level Frequencies



Next we must determine whether the White 3 PACU has adequate capacity to accommodate the inpatient PACU demand.

5.3.2.2 White 3 PACU

The White 3 PACU can accommodate up to 28 recovery patients at one time. In addition to the post-operative recoveries, the White PACU is also used for some pre-operative patients as well as the Electroconvulsive Therapy (ECT) program. These patient flows were included in the simulation so that simulated occupancies reflect the total number of patients in White 3 PACU at any given time. Both pre-operative and ECT patients primarily occupy White in the morning, which aligns well with using White as the primary inpatient recovery PACU[34]. Since inpatient recoveries tend to be longer and inpatients often wait in the PACU for a hospital bed, it is essential that we determine if the capacity exists in White to recover the inpatient post-operative population[35].

A similar analysis to that performed with Ellison 3 PACU demonstrates that the physical capacity within White 3 is adequate to care for the inpatient population. Transitioning White from a mix of outpatient and inpatient recoveries to only inpatients increases average occupancy by approximately 6%. The results indicate that occupancy levels remain below the physical capacity of 28 beds. One key assumption is that

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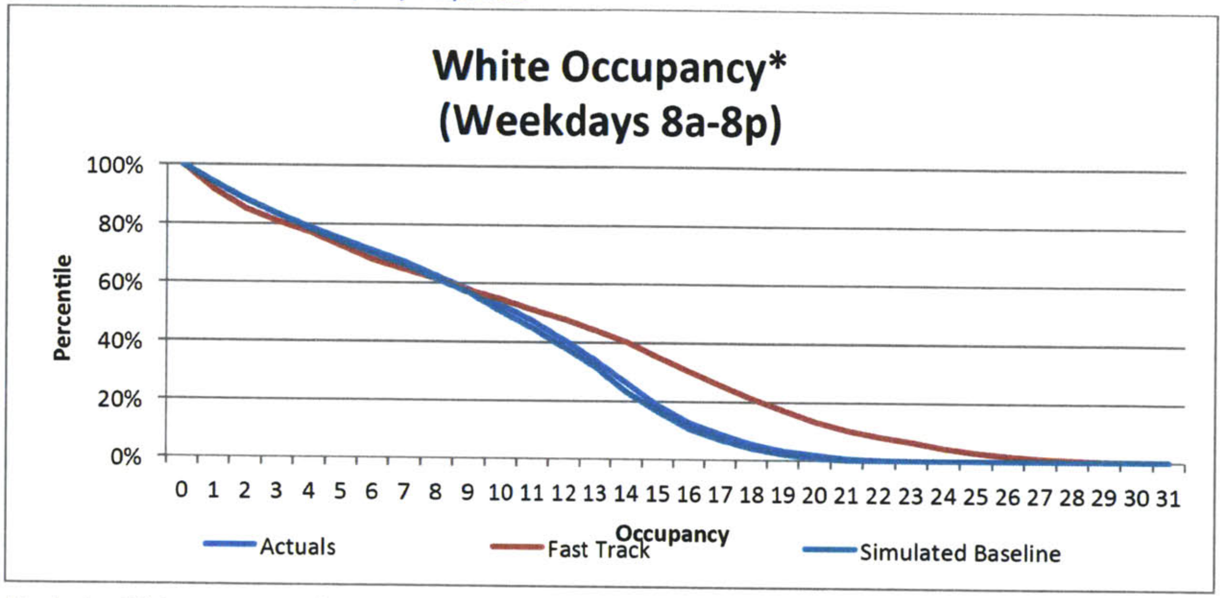
[34] In general, inpatient surgeries are longer than outpatient. This leads to greater inpatient PACU demand later in the day.

[35] This does not include the pediatric inpatients and PACU overnighter that must be routed to Ellison 3 PACU for private recovery slots.

recovery time for inpatients will not increase in an all-inpatient PACU. Since the downstream hospital bed is the gating factor for inpatient length of stay, we assume that an all-inpatient PACU will not increase the inpatient PACU length of stay. Figure 15 displays the occupancy frequencies experienced in the White 3 PACU under the current scenario with the "Fast Track" routing in place (i.e., all inpatients routed to White 3 PACU). See the appendix for White 3 PACU occupancy frequencies by two-hour time intervals from 8am to 8pm.

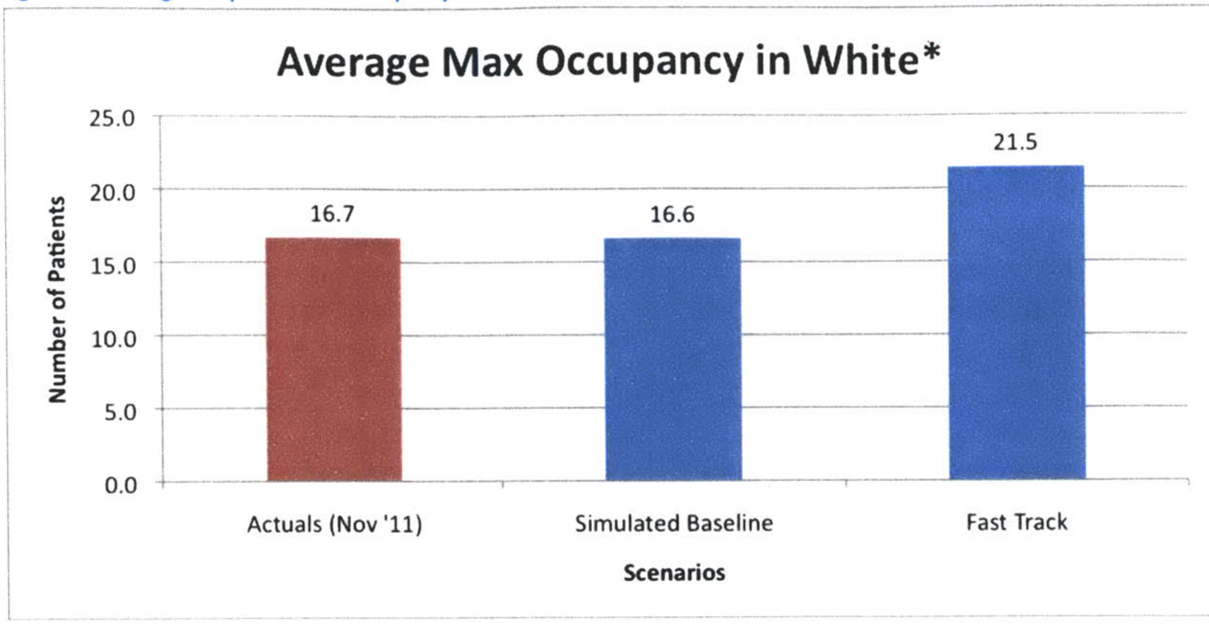
Figure 15: White 3 PACU Total Occupancy Frequencies



*Includes White pre-op and ECT patients as well as the inpatient population

The average daily maximum occupancy within the White 3 PACU also increases from 16.6 to 21.5 patients, but is still well below the physical capacity of 28 beds. We conclude that although average and daily maximum occupancies within White increase, they do not exceed the physical capacity that exists.

Figure 16: Average Daily Maximum Occupancy in White 3 PACU

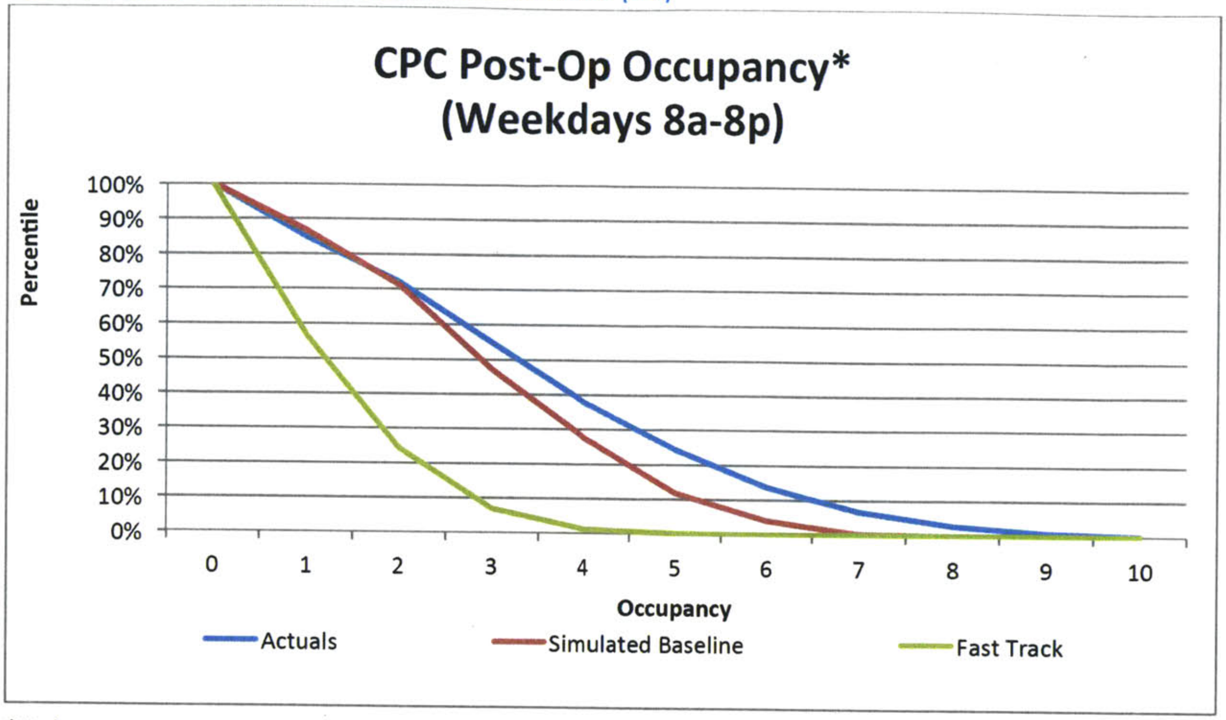


*Includes White pre-op and ECT patients with the inpatient population

The proposed solution is feasible within the current physical constraints present in the Ellison 3 and White 3 PACUs. Indeed the occupancy levels within White increase, but these are offset by the decrease in post-op occupancy in the Phase 2 PACU, the Center for Perioperative Care (CPC).

In the current system, almost all of the outpatients are routed to the CPC for phase 2 PACU recovery. The proposed solution discharges the majority of the outpatients directly home from the Phase 1 PACU (one-step recovery process). This dramatically reduces the occupancy levels in the CPC. The only remaining outpatients routed to the CPC are those from the Lunder 2 and 4 Phase 1 PACUs. Lunder 2 and 4 remained self-contained in the simulation. Outpatients who recover in these PACUs continue to follow the two-step recovery process, and are therefore routed to the CPC for phase 2 recovery. The team at MGH will consider implementing a one-step recovery process for these outpatients as well after implementation of the Ellison 3 outpatient "Fast Track". Figure 17Figure 17 shows that post-op occupancy in the CPC never exceeds four patients and the average occupancy is less than two patients 76% of the time. This reduction in patient volume in the CPC allows for nursing resources to be reassigned to White 3 PACU to accommodate the expected occupancy increase.

Figure 17: Post-op Occupancy Frequencies in the Phase 2 PACU (CPC)



*Only post-op outpatients in CPC are from Lunder 2 and 4

The results from the discrete event simulation demonstrate that adequate capacity exists to accommodate the proposed "Fast Track" solution. Reassigning PACU nurses from the Phase 2 CPC PACU to the White 3 PACU will allow MGH to care for all inpatients and outpatients in a one-step process. Furthermore, incorporating an outpatient designated, one-step recovery location in the Ellison 3 PACU reduces the average PACU length of stay by 27%, thus increasing overall PACU capacity by 1.8 beds per day.

5.4 Discussion

There is qualitative and quantitative evidence that demonstrates the benefits of the proposed "Fast Track" solution. Segregating the patient populations reduces the variability within each PACU, which allows for greater standardization of work. For outpatients it also increases nurse availability and eliminates handoff delays, inherent to the two-step recovery process. An outpatient "Fast Track" will also allow MGH to leverage lessons learned from MGWest and incorporate outpatient-specific best practices. The decrease in outpatient PACU length of stay of 46 minutes equates to increasing capacity by 1.8 beds per day. Research performed at MGH shows that this apparently small increase in resources dramatically increases patient throughput (Schoenmeyr, et al., 2009). The efficiencies gained by incorporating the outpatient "Fast Track" solution increase capacity without adding additional resources. This leads to improved patient flow and a decrease in patients waiting in the operating room for a PACU slot.

Further research shows that fast-tracking outpatients is a new practice that is being adopted across institutions in the United States. The latest version of *PeriAnesthesia Nursing Standards and Practice Recommendations* (2010-2012) includes, for the first time, a practice recommendation on fast tracking outpatients (American Society of PeriAnesthesia Nurses, 2011). Incorporating outpatient-specific processes significantly reduces the PACU hours required to meet demand and increases total PACU capacity.

Chapter 6: Final Recommendations

6.1 Summary of Recommendations

Based on the analysis performed, MGH should go forward with implementing the outpatient "Fast Track" solution. The "Fast Track" addresses the greatest sources of delay currently present at MGH and enables further process improvement by incorporating best practices from the MGWest Surgery Center. Based on the simulation results, we recommend locating the outpatient "Fast Track" in the Ellison 3 PACU and routing all inpatients to the White 3 PACU. Designating eight beds in the Ellison 3 PACU is sufficient to satisfy demand 85% of the time. MGH should designate eight beds as the baseline for the "Fast Track" and flex the actual number of outpatient-designated beds up or down depending on daily or hourly demand.

Once the basic structure of the "Fast Track" is in place, MGH can incorporate additional process improvements currently in practice at MGWest. These should include:

1. Determining that a patient is clinically ready for discharge based on meeting discharge criteria rather than requiring anesthesia signoff.
2. Having a patient sit upright in a recliner upon reaching the discharge criteria.
3. Having escorts present for discharge teaching to expedite the discharge process.

These operational changes will drive further efficiency gains that can reduce the average outpatient length of stay by 46 minutes or more. More ambitious process improvement initiatives should be investigated once the "Fast Track" is established. The proposed "Fast Track" system is the foundation for building a culture and workflow focused on high throughput.

6.2 Implementation Challenges

While the proposed "Fast Track" solution may seem straightforward on paper, there are a few key challenges anticipated during implementation. First, all of the relevant stakeholders must buy in to the proposed solution. These individuals have been involved and updated along the way, but final approval on the proposed changes is essential.

Nursing resources should be reassigned from the Center for Perioperative Care (CPC) to the White 3 PACU. Shifting to single-step outpatient recoveries will greatly reduce the required resources in the CPC while increasing staffing needs in the White 3 PACU. Endorsement by all stakeholders is critical for this organizational change, as these two nursing populations report to separate nursing directors. Therefore, all members of PACU nurse management must be on board.

Addressing the logistical concerns that will arise with the proposed solution will also be important for successful implementation. The biggest logistical change is that we are moving the physical location of final outpatient discharges. This requires updated processes for managing personal belongings and the flow of patient escorts in the new system. While these logistical concerns may seem trivial, in order to be successful they must be well defined prior to going live.

6.3 Next Steps

First and foremost, the MGH-MIT collaborative team must present the proposed "Fast Track" solution to the PACU nursing management team, address any concerns and gain approval. This may require small changes to the proposed fast track solution based on feedback from the PACU management team. Next, the solution needs to be presented to all of the PACU nursing staff to explain the benefits and provide an opportunity for feedback and suggestions. Once the solution has been vetted and PACU management and staff are comfortable, the logistical concerns discussed above must be addressed and new processes defined. In addition to widespread communication, a site visit to MGWest for selected frontline nurses prior to implementation will increase employee engagement in the change. Observing the high throughput, outpatient-specific practices at MGWest will demonstrate the benefits of the "Fast Track" while addressing concerns on how it will actually function. Once all parties involved have bought in and are prepared for the change, the team can move forward with nursing reassignments and final implementation.

After implementation, the team will continue to monitor performance and PACU length of stay data and identify opportunities for continuous improvement within the "Fast Track" environment. Implementing a one-step recovery for Lunder 2 and 4 outpatients as well would eliminate the need to have any post-op patients visit the Center for Perioperative Care (CPC). The CPC could then be 100% dedicated to patient check-in and pre-operative processing. Since the CPC is currently located on the 12th floor of Ellison and White, reducing patient transports to this unit from the Phase 1 PACUs on the 3rd floor results in significant time savings.

There are also few long-term next steps to further optimize patient flow with an established "Fast Track." The team will consider the feasibility of relocating the physical location of the "Fast Track" to the new CPC when it opens in Wang 3 at the end of 2012. By implementing the "Fast Track" now in Ellison 3, the team will be able to determine if the capacity will exist in the new CPC to house the "Fast Track." Finally, the team is now initiating a project to look at intra-day operating room scheduling and the resulting PACU volumes with the hope of level-loading each PACU throughout the day. The goal is to minimize the daily peak occupancies and have a more steady and consistent flow of patients into the PACUs throughout the day. Since the proposed "Fast Track" solution separates the inpatients and outpatients into distinct PACUs, the intra-day scheduling will seek to level the patient volumes for each population respectively. Reducing the variability in PACU occupancies will further improve PACU efficiency and increase patient throughput.

Chapter 7: Appendix

7.1 Sample Patient PACU Length of Stay Data

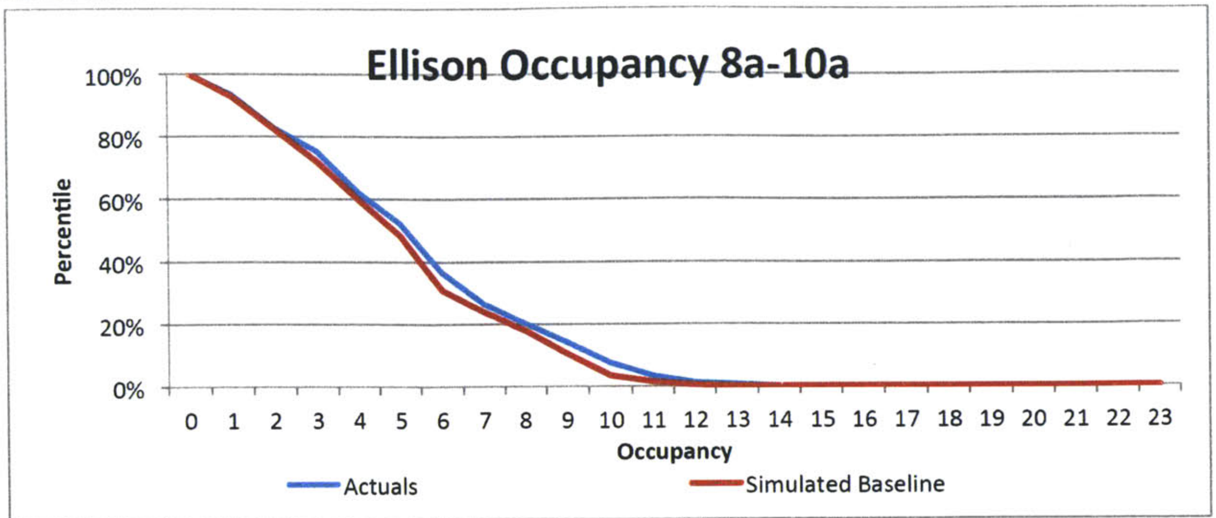
Unit	Overnight_Req	PT_Category	PACU_Arrived	Ready to Depart Time	Depart Time	surgery_proc_complete_date	patient_leaves_or_date	ASA_class	actual_or
MOR	N	AMBULATORY	1/1/10 1:15	1/1/10 2:09	1/1/10 2:56	1/1/10 0:55	1/1/10 1:06	IV	27
MOR	N	INPATIENT	1/1/10 22:01	1/1/10 22:46	1/1/10 22:46	1/1/10 21:45	1/1/10 22:00	II	29
MOR	N	INPATIENT	1/1/10 10:38	1/1/10 11:55	1/1/10 12:58	1/1/10 10:17	1/1/10 10:35	II	23
MOR	N	SAME DAY ADMIT	1/1/10 10:34	1/1/10 11:55	1/1/10 11:55	1/1/10 10:14	1/1/10 10:33	II	21
MOR	N	INPATIENT	1/1/10 13:38	1/1/10 16:48	1/1/10 16:48	1/1/10 13:05	1/1/10 13:36	II	38
MOR	N	AMBULATORY	1/1/10 15:59	1/1/10 16:28	1/1/10 16:28	1/1/10 15:45	1/1/10 15:55	II	35
MOR	N	INPATIENT	1/1/10 20:16	1/1/10 22:31	1/1/10 22:31	1/1/10 20:02	1/1/10 20:14	III	37
MOR	N	INPATIENT	1/2/10 9:04	1/2/10 10:47	1/2/10 10:47	1/2/10 8:40	1/2/10 9:02	II	23
MOR	N	SAME DAY ADMIT	1/2/10 9:24	1/2/10 10:29	1/2/10 10:33	1/2/10 9:09	1/2/10 9:22	II	37
MOR	N	INPATIENT	1/2/10 15:21	1/2/10 18:06	1/2/10 18:06	1/2/10 15:00	1/2/10 15:19	II	28
MOR	N	INPATIENT	1/2/10 14:01	1/2/10 16:19	1/2/10 17:01	1/2/10 13:14	1/2/10 13:59	III	27
MOR	N	AMBULATORY	1/2/10 15:37	1/2/10 17:18	1/2/10 17:18	1/2/10 15:30	1/2/10 15:37	II	22
MOR	N	SAME DAY ADMIT	1/2/10 18:22	1/2/10 20:03	1/2/10 20:03	1/2/10 18:05	1/2/10 18:18	II	32
MOR	N	INPATIENT	1/2/10 23:02	1/3/10 3:31	1/3/10 3:31	1/2/10 21:36	1/2/10 22:25	II	27
MOR	N	INPATIENT	1/2/10 13:42	1/2/10 16:03	1/2/10 16:23	1/2/10 13:24	1/2/10 13:39	II	37
MOR	N	AMBULATORY	1/2/10 11:15	1/2/10 12:19	1/2/10 12:36	1/2/10 10:54	1/2/10 11:16	I	5
MOR	N	AMBULATORY	1/2/10 13:03	1/2/10 16:03	1/2/10 16:03	1/2/10 12:55	1/2/10 13:03	II	22
MOR	N	AMBULATORY	1/2/10 18:16	1/2/10 20:20	1/2/10 20:20	1/2/10 17:59	1/2/10 18:12	III	14
MOR	N	INPATIENT	1/2/10 10:08	1/2/10 11:39	1/2/10 11:39	1/2/10 9:39	1/2/10 10:10	I	22
MOR	N	INPATIENT	1/2/10 16:19	1/2/10 20:42	1/2/10 20:42	1/2/10 15:58	1/2/10 16:14	I	37

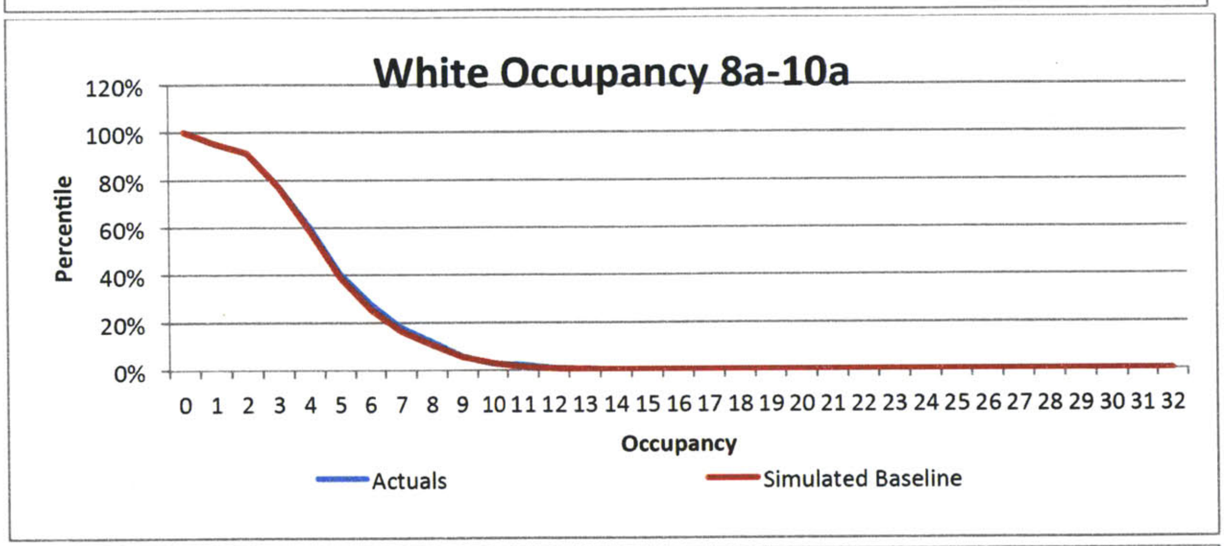
7.2 Additional Statistics for Figure 5: Average PACU length of stay at MGH and MGWest.

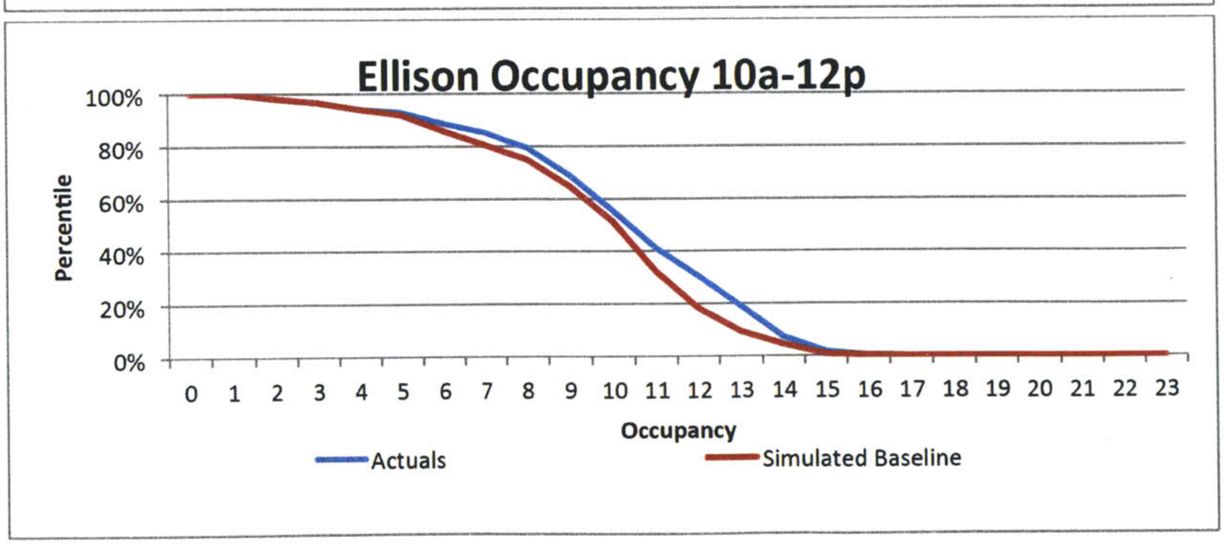
(2010 Data: Orthopedic outpatients discharged home with < 8hr PACU length of stay)

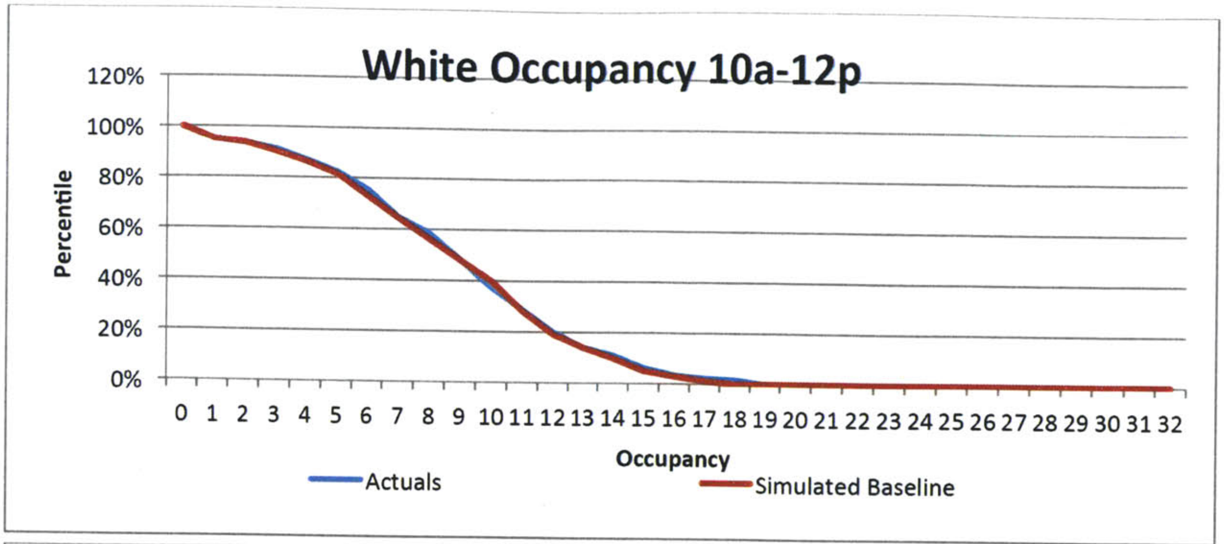
	Surgeon	Dr. A	Dr. B	Dr. C	Dr. B	Dr. C	Dr. D	Dr. D	Dr. C	Dr. E	Dr. B
	Procedure ICD-9Code	7932	8081	8145	8183	8183	8183	8363	8363	8363	8363
Number of Cases	MGWest	26	60	49	66	5	27	79	15	72	76
	SDC	12	22	43	9	12	10	20	26	11	9
Average PACU LOS (hrs)	MGWEST	1.3	1.7	2.0	1.6	1.5	1.8	1.8	2.0	2.0	1.8
	MGH	2.6	3.2	3.6	3.2	3.0	3.2	3.2	3.3	3.1	2.9
Standard Deviation (hrs)	MGWest	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.5	0.5	0.5
	SDC	0.9	1.4	1.0	1.4	1.1	1.0	1.0	0.8	0.8	0.6
Coefficient of Variation	MGWest	0.4	0.3	0.2	0.2	0.3	0.2	0.2	0.2	0.3	0.3
	SDC	0.3	0.4	0.3	0.4	0.4	0.3	0.3	0.2	0.3	0.2
Minimum (hrs)	MGWest	0.7	1	1.1	1	1	0.9	1	1.1	1	0.8
	SDC	1.1	1.8	1.7	1.3	1.8	1.9	1.2	2.1	1.4	2.1
Maximum (hrs)	MGWest	2.6	3.2	2.8	3.2	2.1	2.6	3.1	2.8	3.4	4.6
	SDC	4.1	7.8	6.7	5.4	5.4	5.4	5	4.6	4.1	4.1

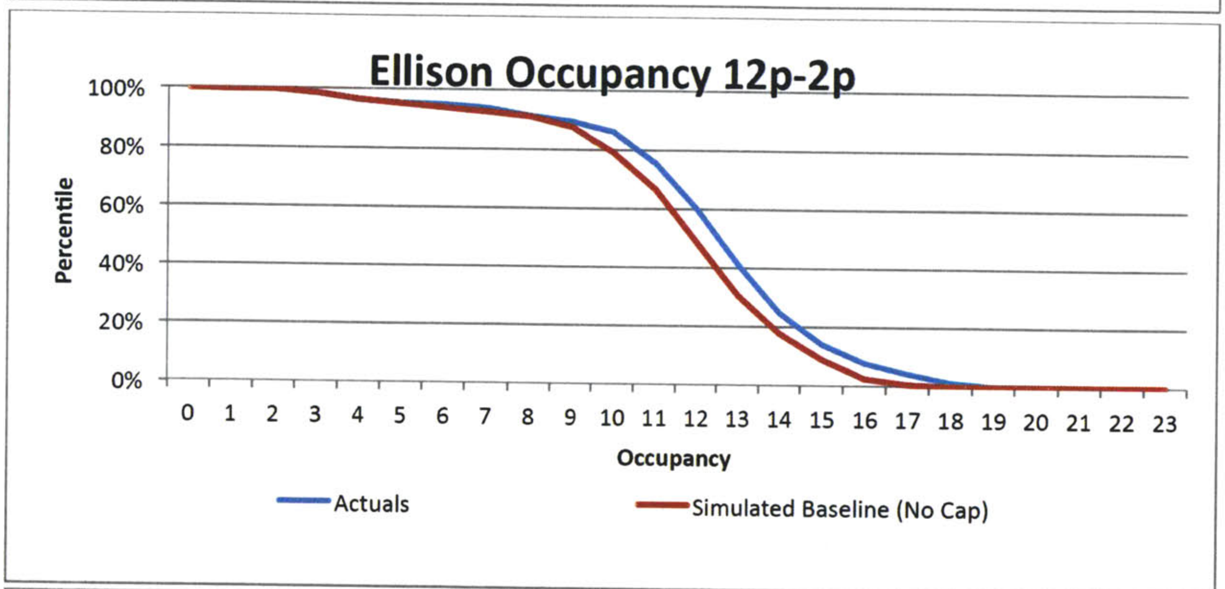
7.3 Actual and Simulated Baseline Occupancy Frequencies by two-hour time intervals

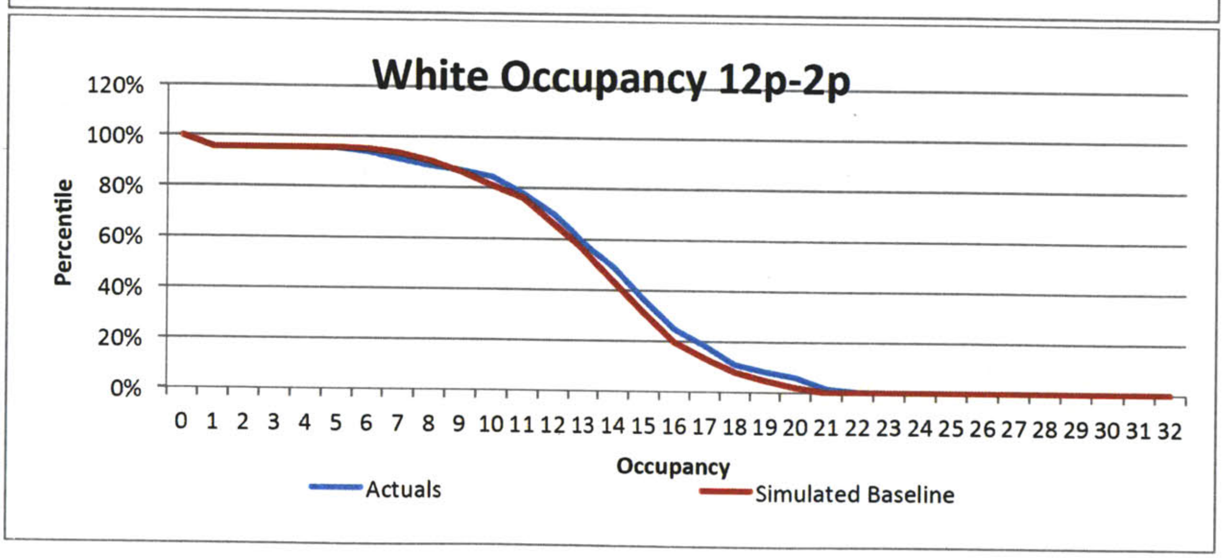


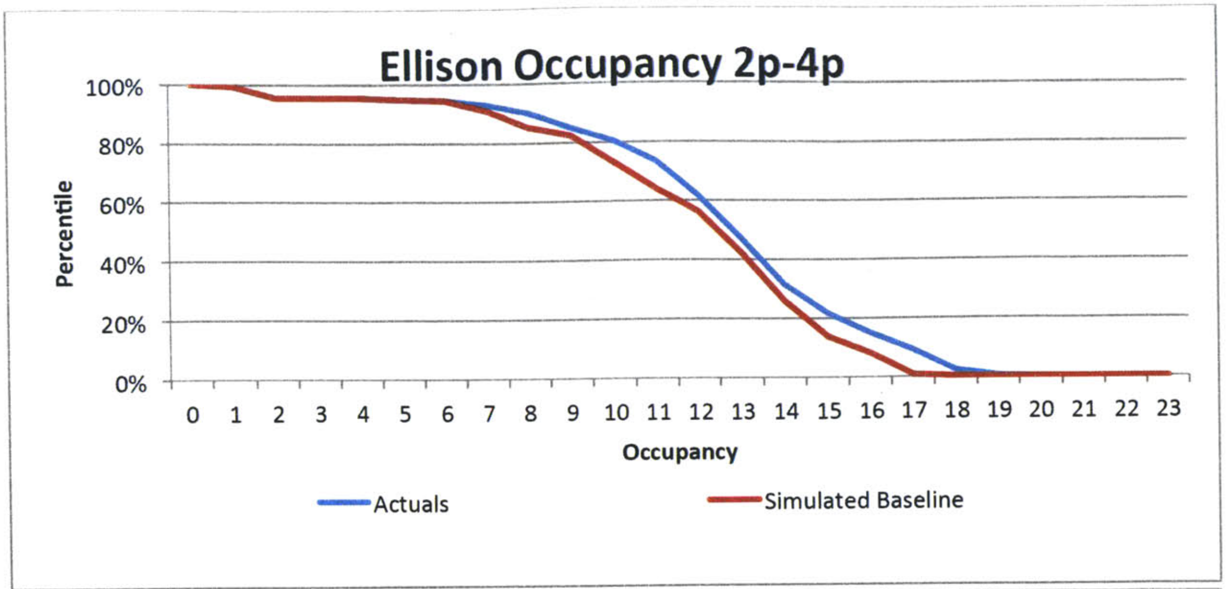


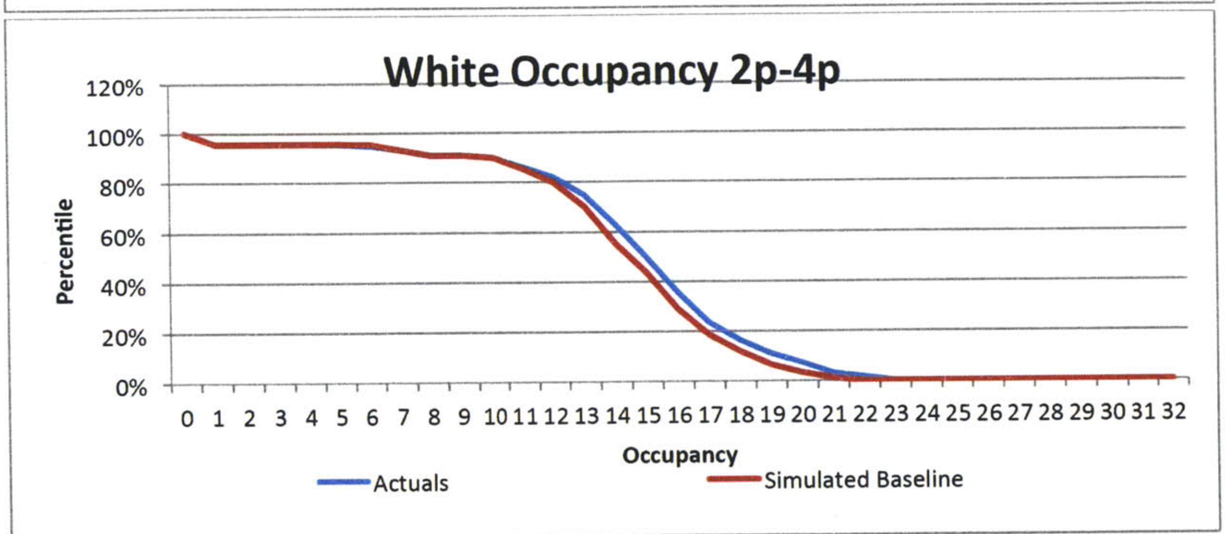


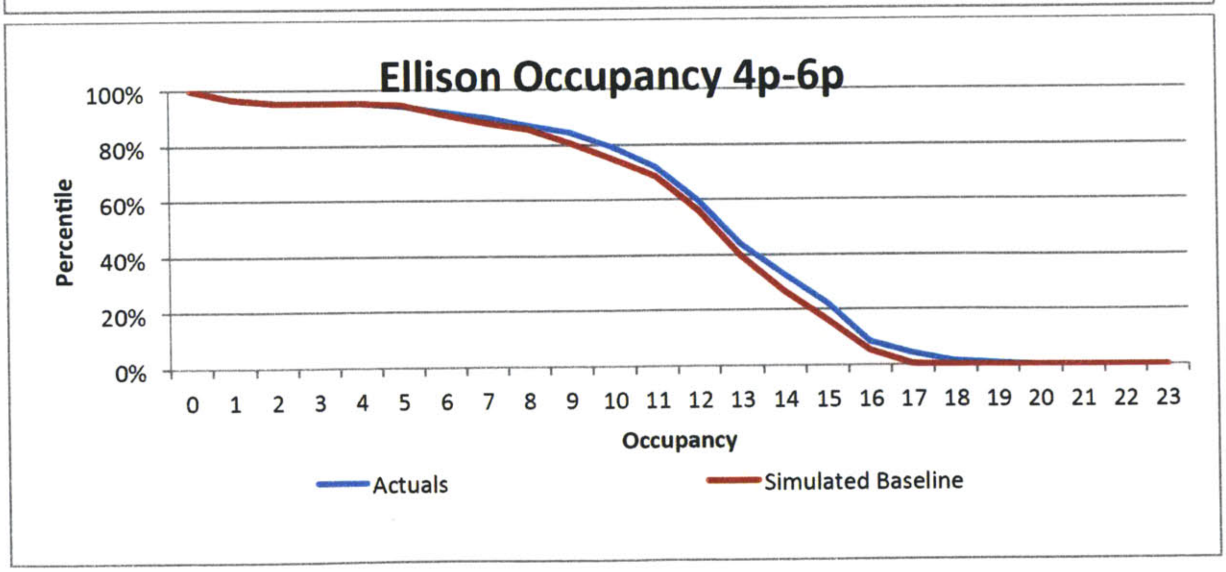

White Occupancy 10a-12p
120%
100%
80%
60%
40%
20%
0%
Percentile
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32
Occupancy
Actuals
Simulated Baseline

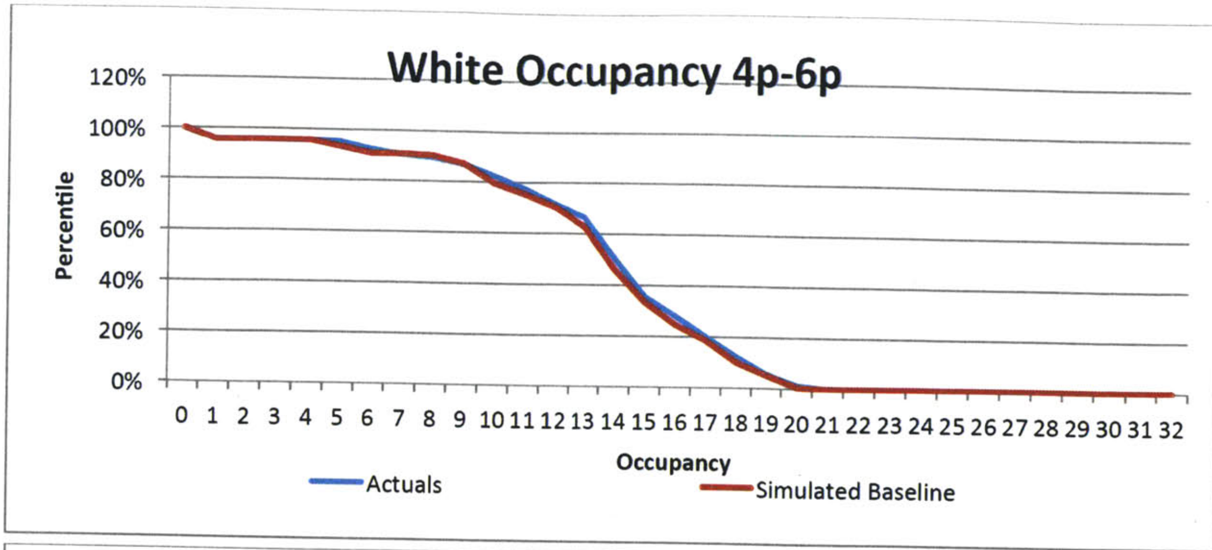

Ellison Occupancy 12p-2p
100%
80%
60%
40%
20%
0%
Percentile
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Occupancy
Actuals
Simulated Baseline (No Cap)

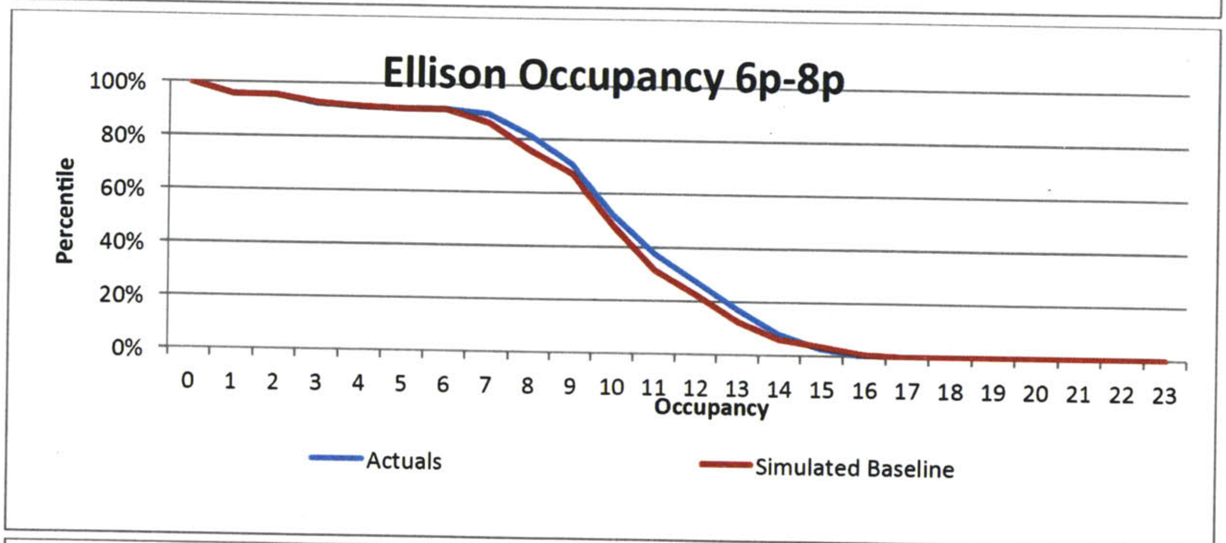

White Occupancy 12p-2p
120%
100%
80%
60%
40%
20%
0%
Percentile
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32
Occupancy
Actuals
Simulated Baseline

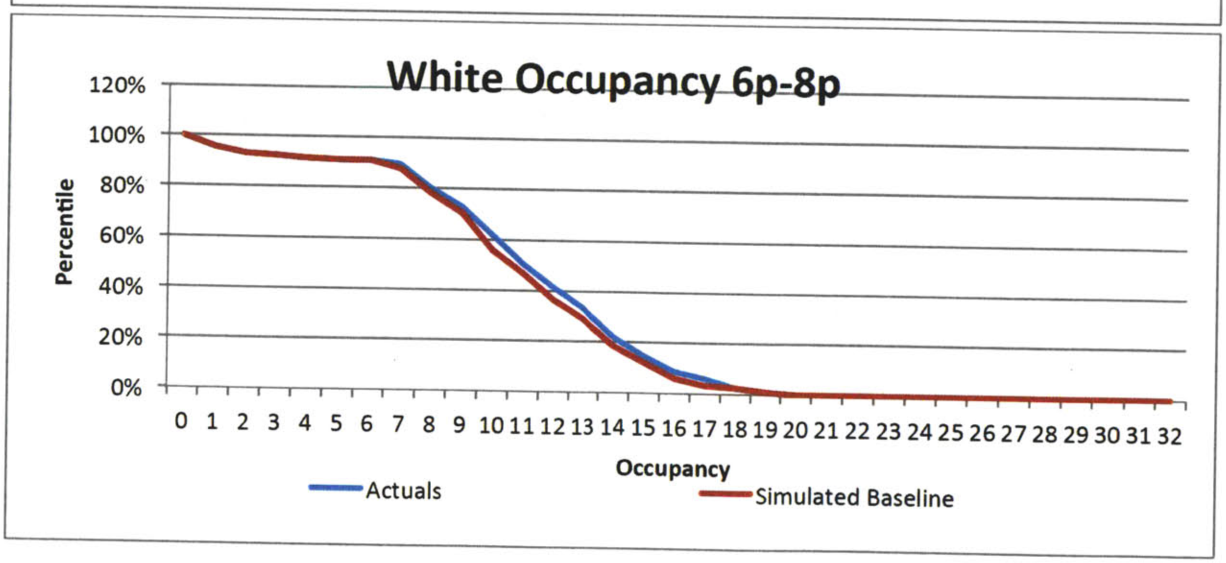

Ellison Occupancy 2p-4p
Percentile
100%
80%
60%
40%
20%
0%
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Occupancy
Actuals
Simulated Baseline


White Occupancy 2p-4p
Percentile
120%
100%
80%
60%
40%
20%
0%
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32
Occupancy
Actuals
Simulated Baseline

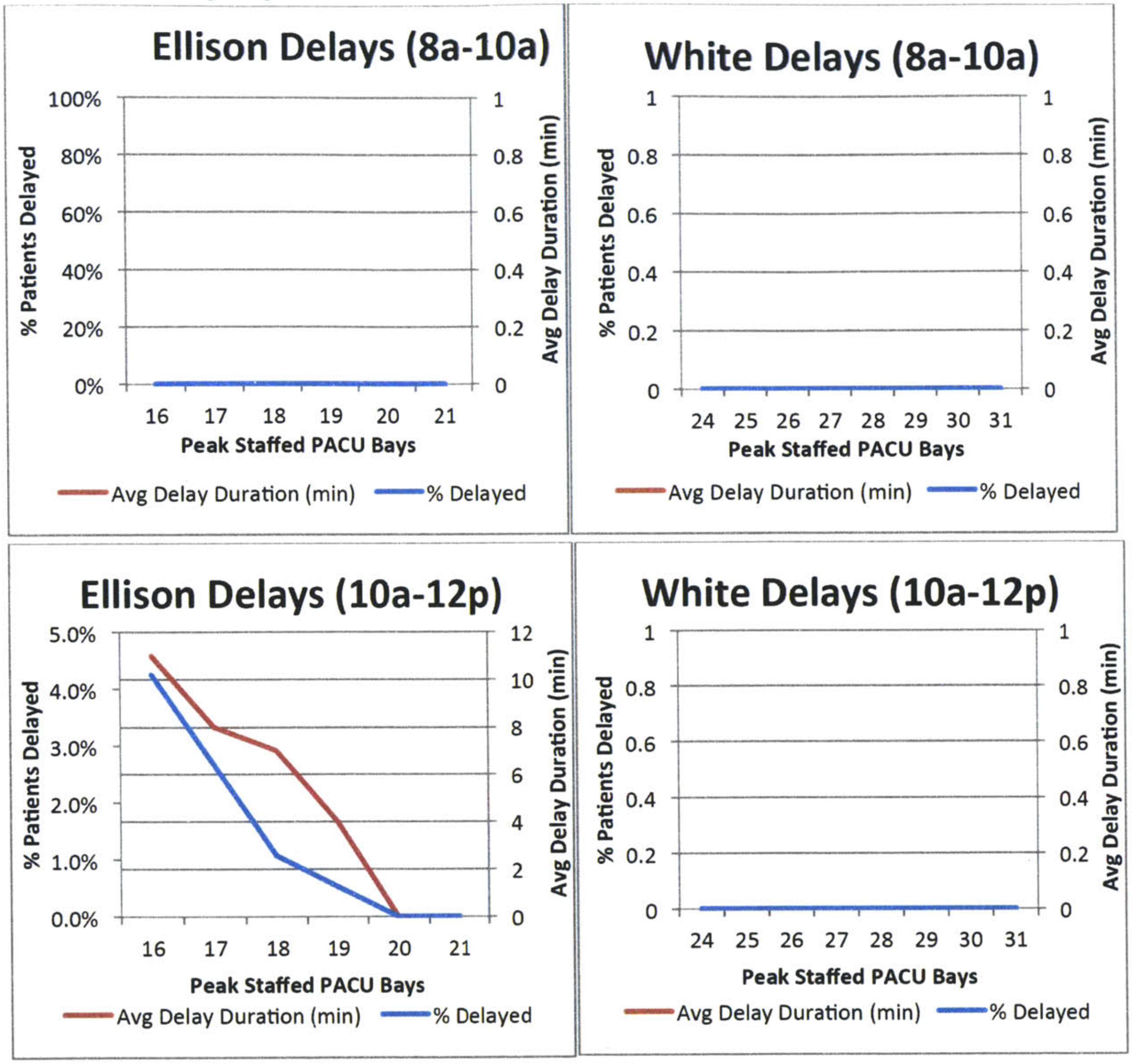

Ellison Occupancy 4p-6p
Percentile
100%
80%
60%
40%
20%
0%
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Occupancy
Actuals
Simulated Baseline

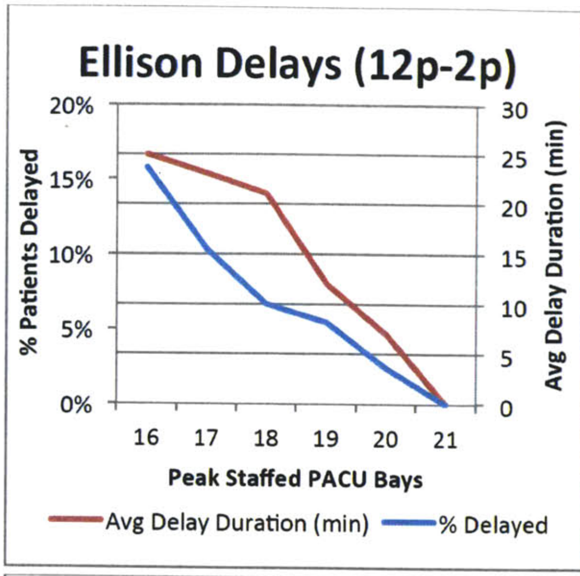

White Occupancy 4p-6p
120%
100%
80%
60%
40%
20%
0%
Percentile
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32
Occupancy
Actuals
Simulated Baseline

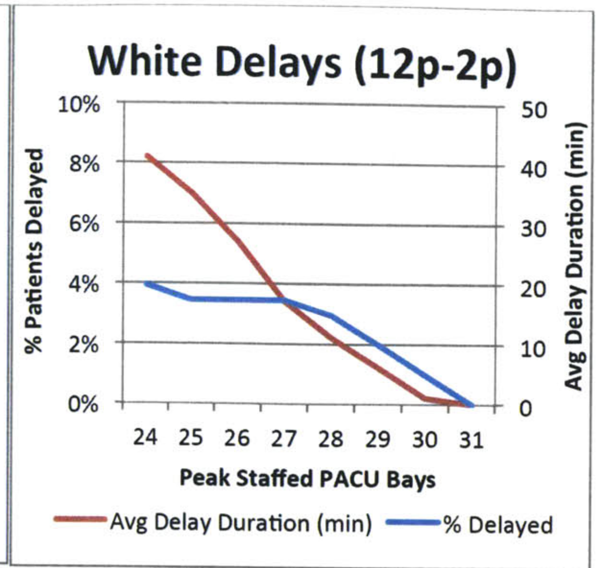

Ellison Occupancy 6p-8p
100%
80%
60%
40%
20%
0%
Percentile
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Occupancy
Actuals
Simulated Baseline

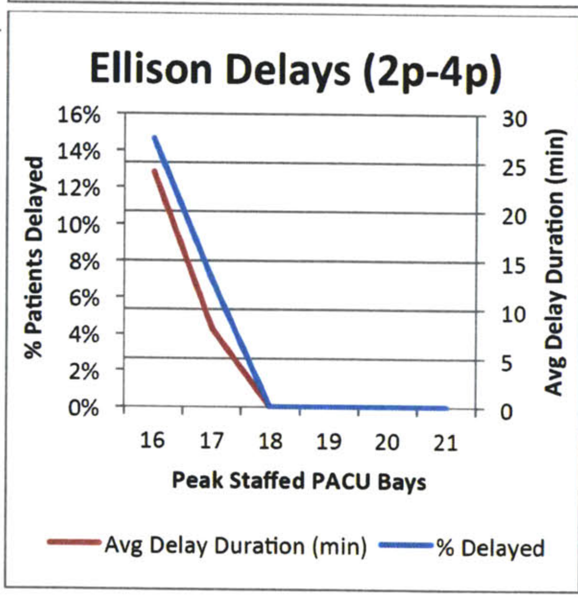

White Occupancy 6p-8p
120%
100%
80%
60%
40%
20%
0%
Percentile
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32
Occupancy
Actuals
Simulated Baseline

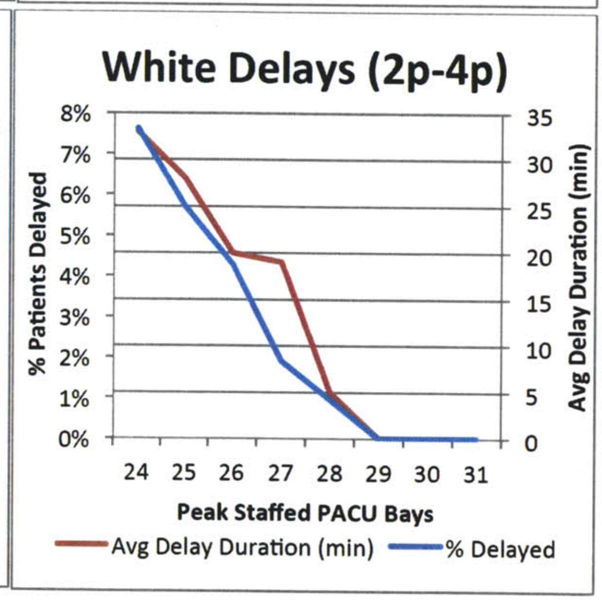
7.4 PACU Delays by Peak Staffed PACU Bays: Two-hour time intervals

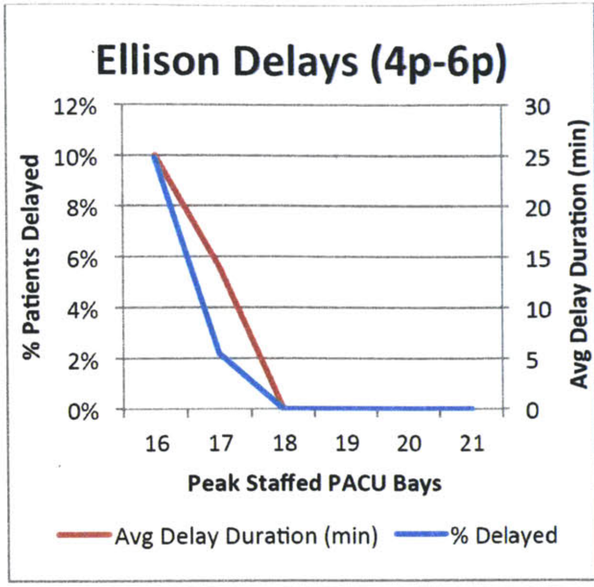


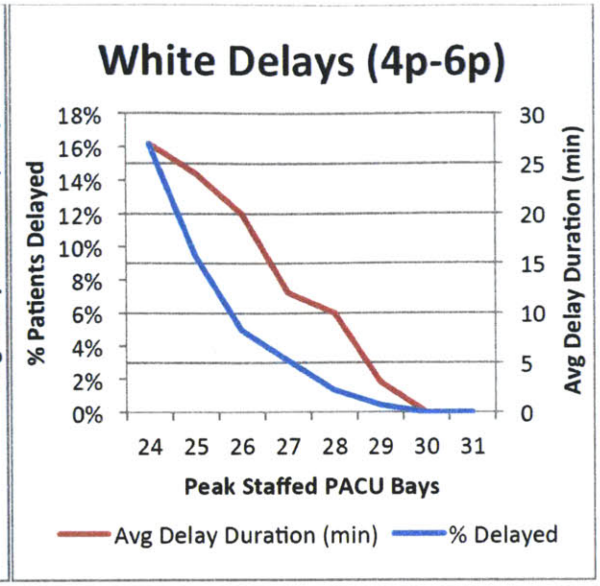

Ellison Delays (12p-2p)
% Patients Delayed
Avg Delay Duration (min)
Peak Staffed PACU Bays
Avg Delay Duration (min)
% Delayed

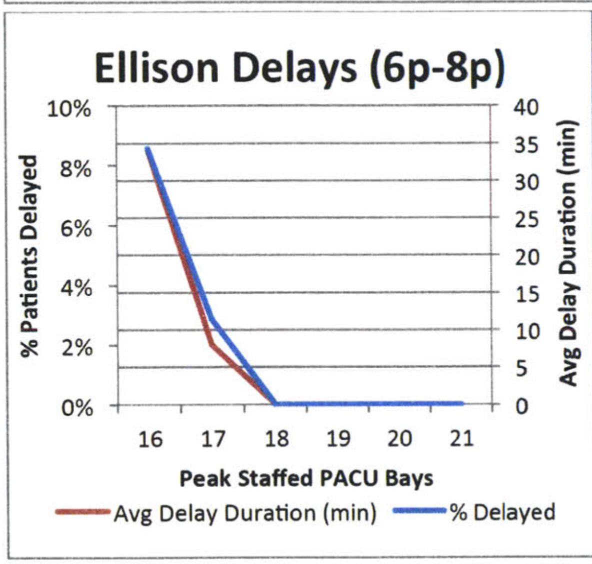

White Delays (12p-2p)
% Patients Delayed
Avg Delay Duration (min)
Peak Staffed PACU Bays
Avg Delay Duration (min)
% Delayed

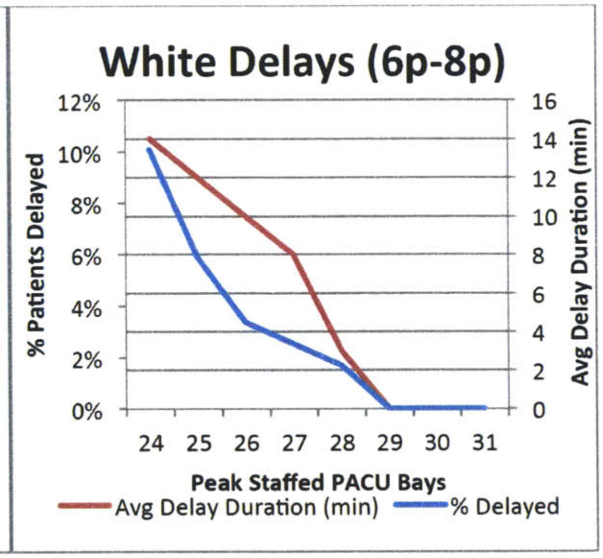

Ellison Delays (2p-4p)
% Patients Delayed
Avg Delay Duration (min)
Peak Staffed PACU Bays
Avg Delay Duration (min)
% Delayed


White Delays (2p-4p)
% Patients Delayed
Avg Delay Duration (min)
Peak Staffed PACU Bays
Avg Delay Duration (min)
% Delayed

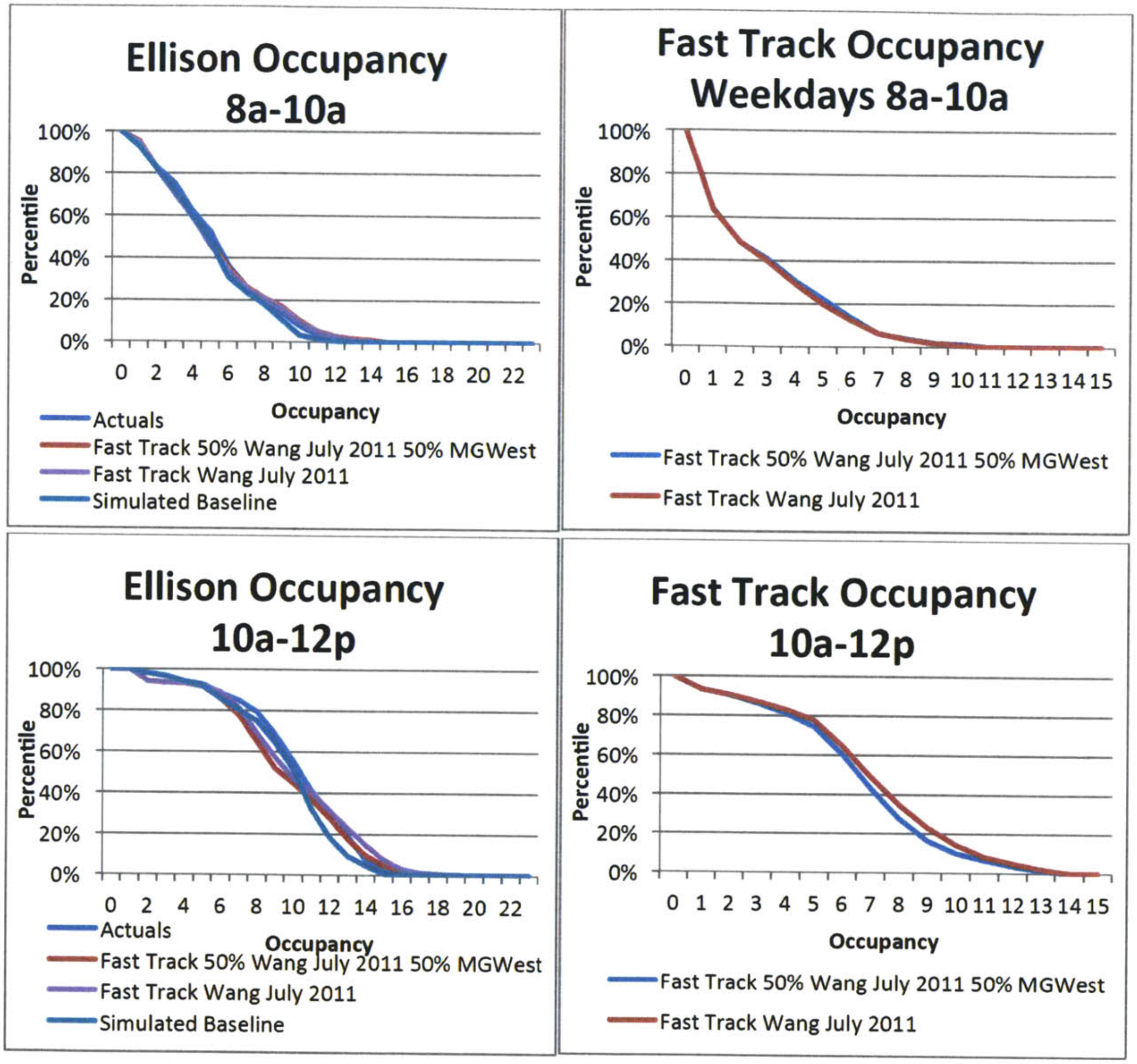

Ellison Delays (4p-6p)
% Patients Delayed
12%
10%
8%
6%
4%
2%
0%
30
25
20
15
10
5
0
Avg Delay Duration (min)
16 17 18 19 20 21
Peak Staffed PACU Bays
Avg Delay Duration (min)
% Delayed

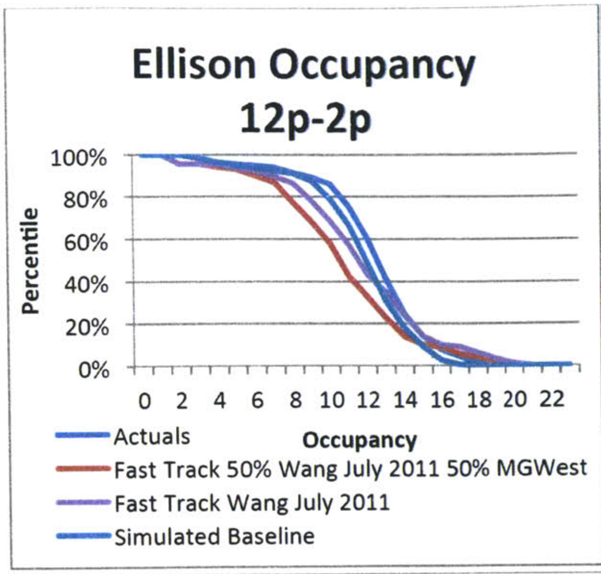

White Delays (4p-6p)
% Patients Delayed
18%
16%
14%
12%
10%
8%
6%
4%
2%
0%
30
25
20
15
10
5
0
Avg Delay Duration (min)
24 25 26 27 28 29 30 31
Peak Staffed PACU Bays
Avg Delay Duration (min)
% Delayed


Ellison Delays (6p-8p)
% Patients Delayed
10%
8%
6%
4%
2%
0%
40
35
30
25
20
15
10
5
0
Avg Delay Duration (min)
16 17 18 19 20 21
Peak Staffed PACU Bays
Avg Delay Duration (min)
% Delayed

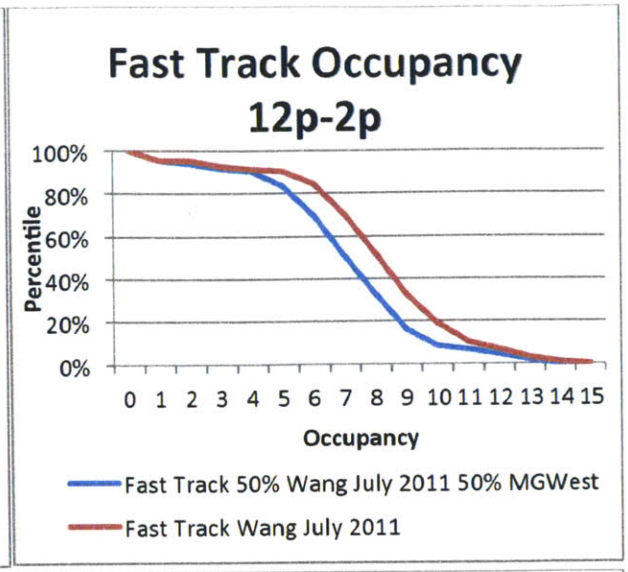

White Delays (6p-8p)
% Patients Delayed
12%
10%
8%
6%
4%
2%
0%
16
14
12
10
8
6
4
2
0
Avg Delay Duration (min)
24 25 26 27 28 29 30 31
Peak Staffed PACU Bays
Avg Delay Duration (min)
% Delayed

7.5 Ellison Total and Fast Track Occupancy Frequencies by two-hour time intervals

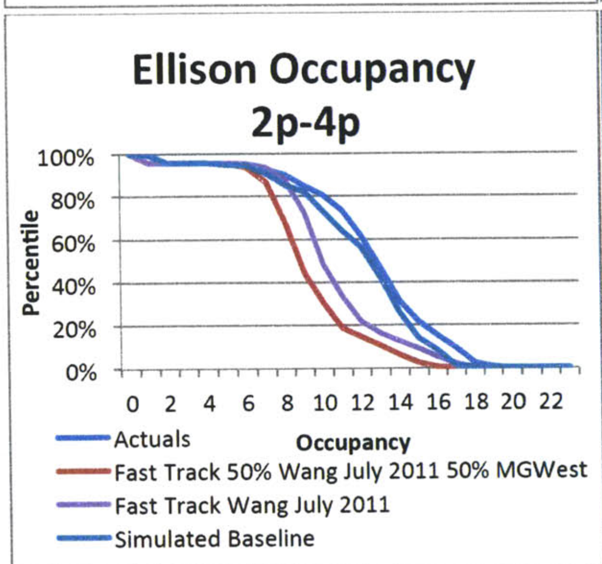




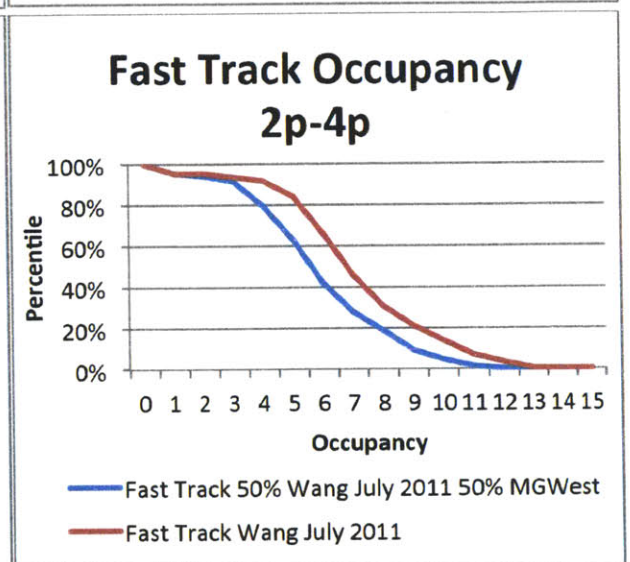
Ellison Occupancy 12p-2p
Percentile
100%
80%
60%
40%
20%
0%
0 2 4 6 8 10 12 14 16 18 20 22
Occupancy
Actuals
Fast Track 50% Wang July 2011 50% MGWest
Fast Track Wang July 2011
Simulated Baseline



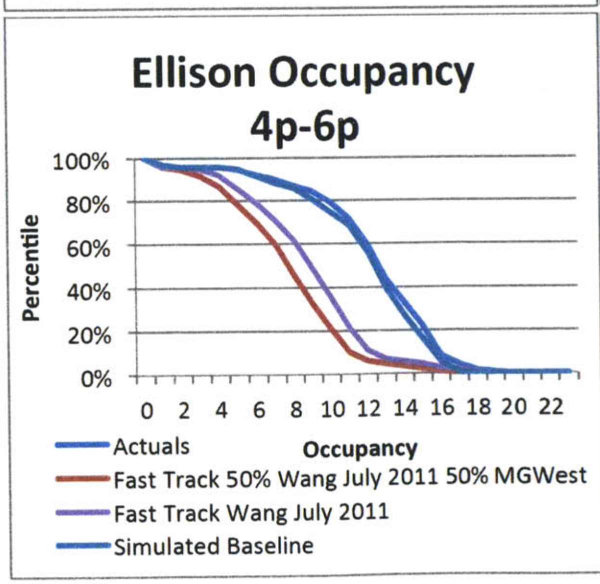
Fast Track Occupancy 12p-2p
Percentile
100%
80%
60%
40%
20%
0%
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Occupancy
Fast Track 50% Wang July 2011 50% MGWest
Fast Track Wang July 2011



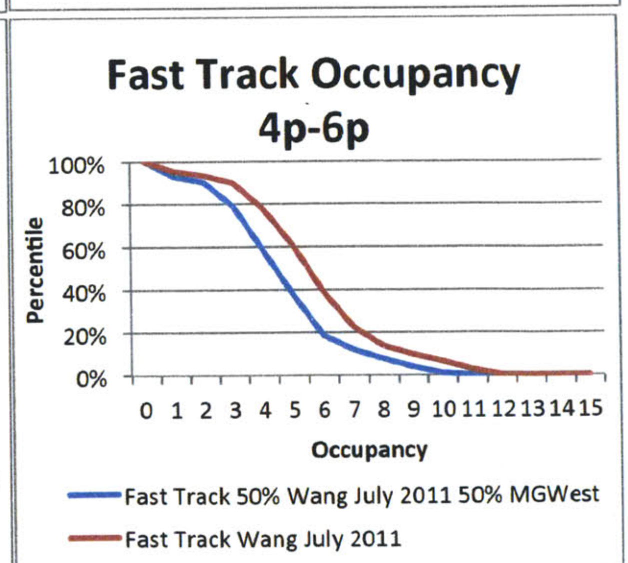
Ellison Occupancy 2p-4p
Percentile
100%
80%
60%
40%
20%
0%
0 2 4 6 8 10 12 14 16 18 20 22
Occupancy
Actuals
Fast Track 50% Wang July 2011 50% MGWest
Fast Track Wang July 2011
Simulated Baseline



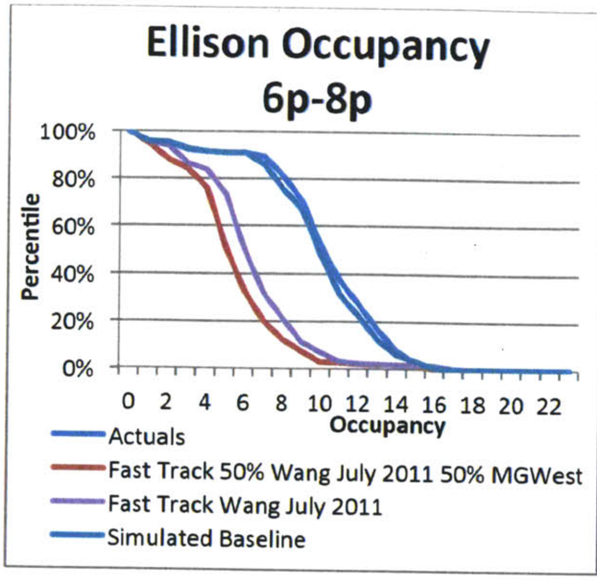
Fast Track Occupancy 2p-4p
Percentile
100%
80%
60%
40%
20%
0%
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Occupancy
Fast Track 50% Wang July 2011 50% MGWest
Fast Track Wang July 2011

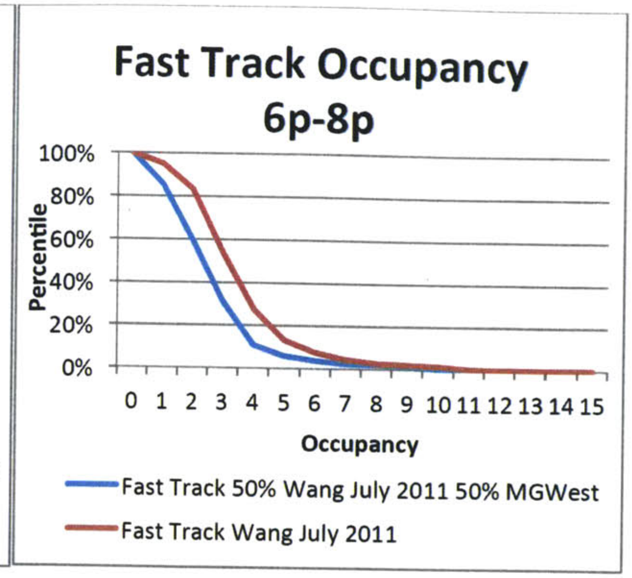


Ellison Occupancy 4p-6p
Percentile
100%
80%
60%
40%
20%
0%
0 2 4 6 8 10 12 14 16 18 20 22
Occupancy
Actuals
Fast Track 50% Wang July 2011 50% MGWest
Fast Track Wang July 2011
Simulated Baseline

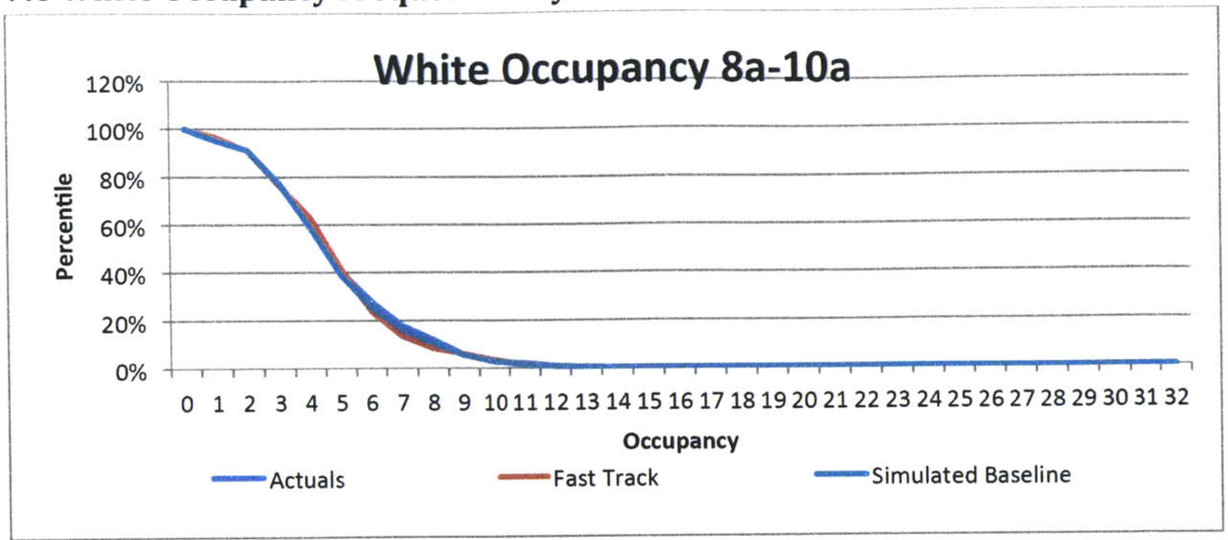


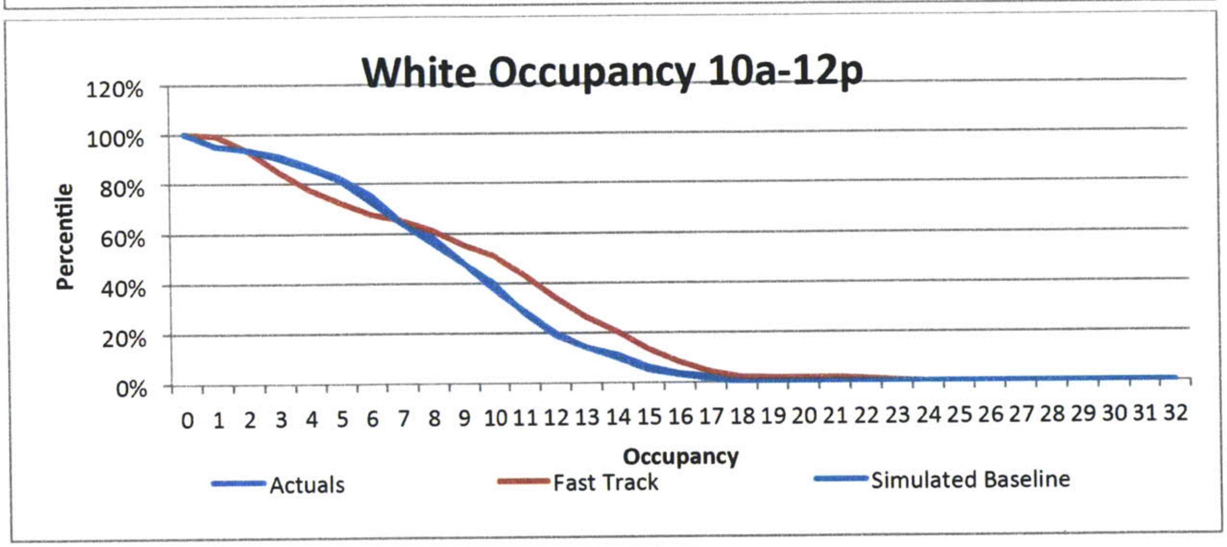
Fast Track Occupancy 4p-6p
Percentile
100%
80%
60%
40%
20%
0%
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Occupancy
Fast Track 50% Wang July 2011 50% MGWest
Fast Track Wang July 2011

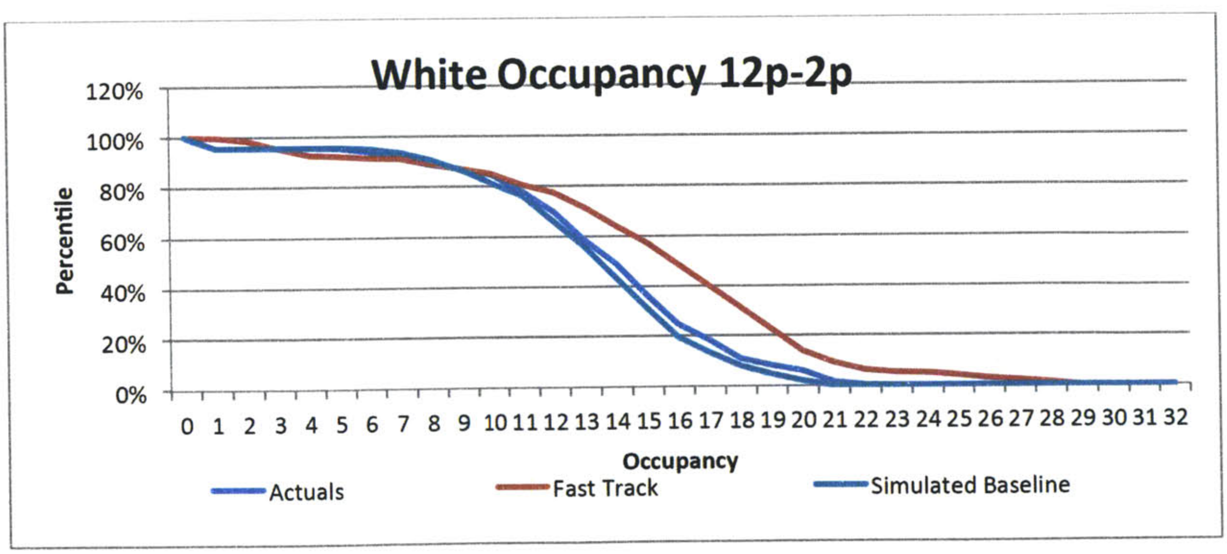

Ellison Occupancy
6p-8p
100%
80%
60%
40%
20%
0%
Percentile
0 2 4 6 8 10 12 14 16 18 20 22
Occupancy
Actuals
Fast Track 50% Wang July 2011 50% MGWest
Fast Track Wang July 2011
Simulated Baseline

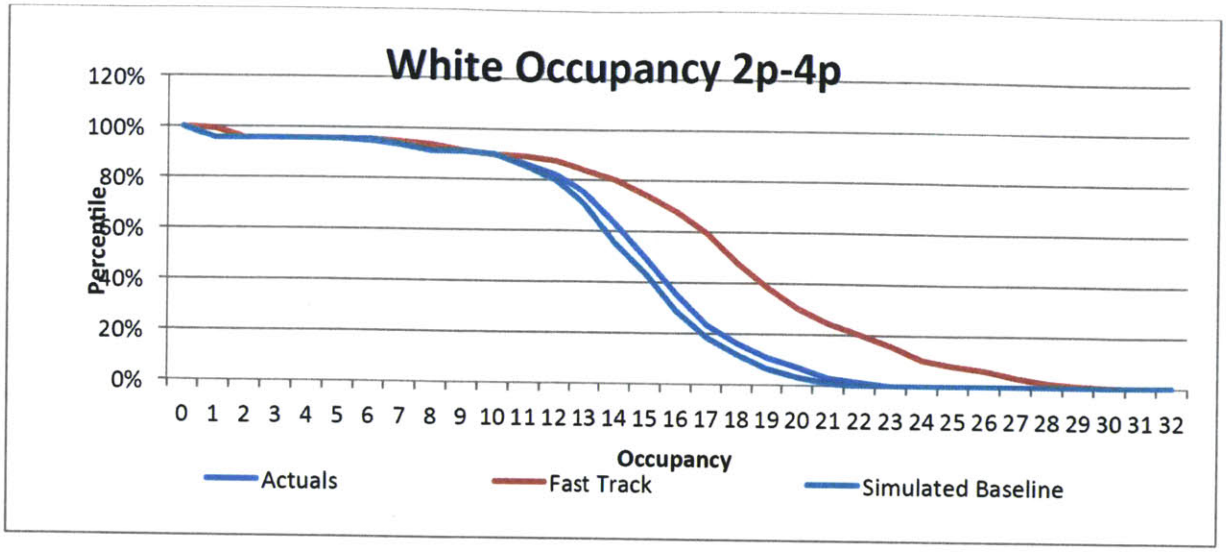

Fast Track Occupancy
6p-8p
100%
80%
60%
40%
20%
0%
Percentile
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Occupancy
Fast Track 50% Wang July 2011 50% MGWest
Fast Track Wang July 2011

7.6 White Occupancy Frequencies by two-hour time intervals

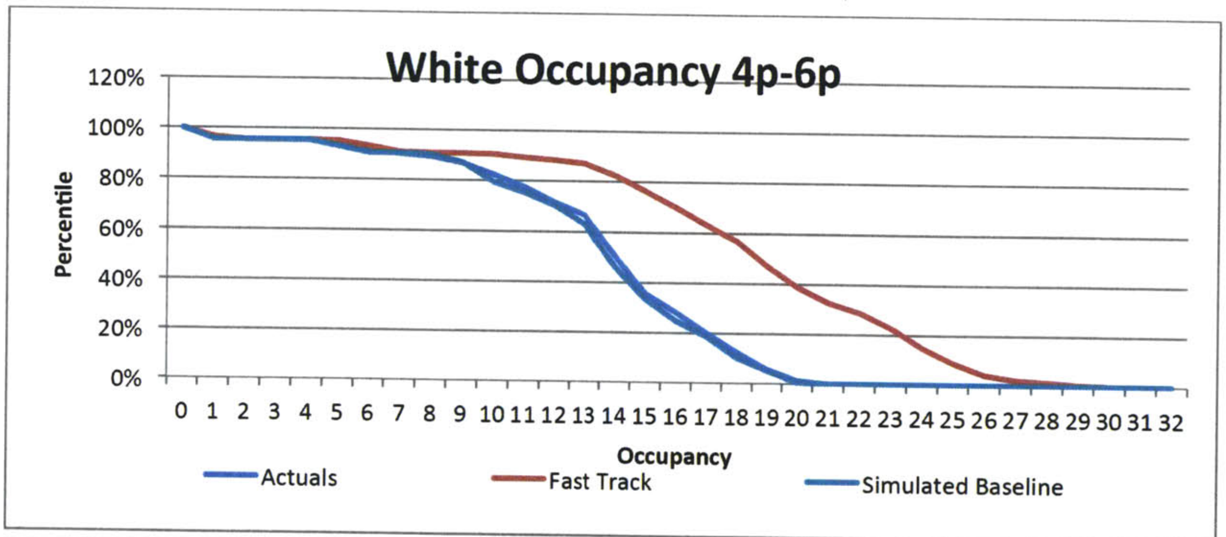




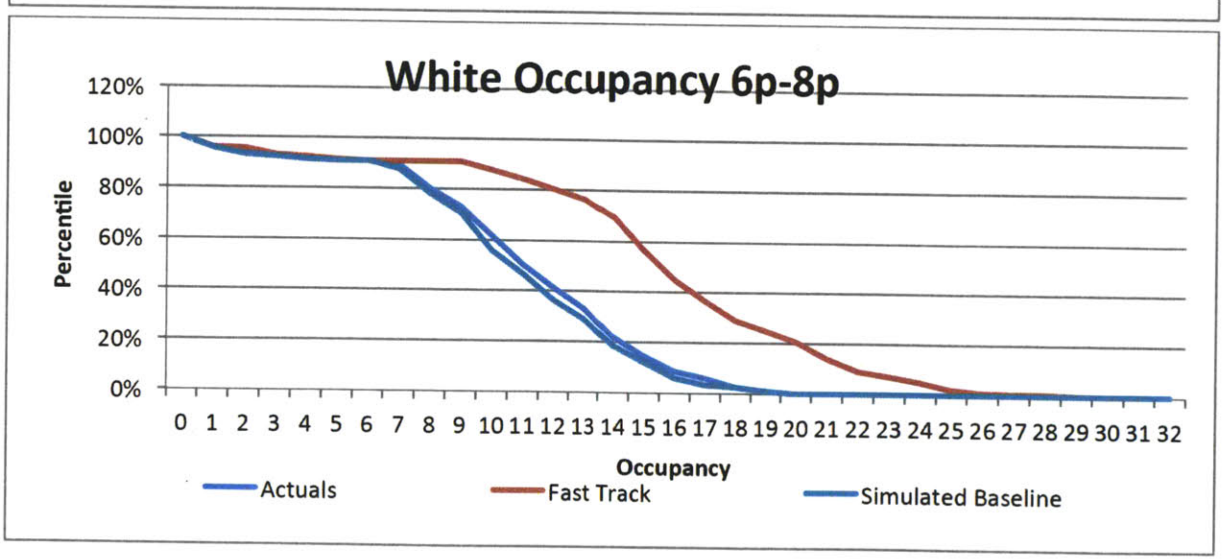




White Occupancy 2p-4p
120%
100%
80%
60%
40%
20%
0%
Percentile
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32
Occupancy
Actuals
Fast Track
Simulated Baseline



White Occupancy 4p-6p
120%
100%
80%
60%
40%
20%
0%
Percentile
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32
Occupancy
Actuals
Fast Track
Simulated Baseline



White Occupancy 6p-8p
120%
100%
80%
60%
40%
20%
0%
Percentile
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32
Occupancy
Actuals
Fast Track
Simulated Baseline

Works Cited

American Society of PeriAnesthesia Nurses. (2011). *ASPAN Standards*. Retrieved January 25, 2012, from ASPAN Website: https://www.aspan.org/ClinicalPractice/ASPANStandards/tabid/3258/Default.aspx

Emanuel, E. (2011, November 20). Saving by the Bundle. *The New York Times*.

Haraden, C., & Resar, R. (2004). Patient Flow in Hospitals: Understanding and Controlling It Better. *Frontiers*, 3-15.

Massachusetts General Hospital. (2012, January 16). *Hospital Overview*. Retrieved January 16, 2012, from www.massgeneral.org: http://www.massgeneral.org/about/overview.aspx

Price, D. (2011). *Managing Variability in Perioperative Process at MGH*. Cambridge: Massachusetts Institute of Technology.

ProModel. (2012). *About Us: Promodel*. Retrieved January 18, 2012, from ProModel Website: www.promodel.com/aboutus/

Schoenmeyr, T., Dunn, P., Gamarnik, D., Levi, R., Berger, D., Daily, B., et al. (2009, June). A Model for Understanding the Impacts of Demand and Capacity on Waiting Time to Enter a Congested Recovery Room. *Anesthesiology*, pp. 110: 1293-1304.

The Advisory Board Company. (2011). *The Advisory Board Company*. Retrieved July 15, 2011, from Surgical Profitability Compass: https://compassportal.advisory.com/wps/portal/

The Advisory Board Company. (2012). *About Us: The Advisory Board Company*. Retrieved January 16, 2012, from The Advisory Board Company Website: www.advisory.com/About-us

United States Congress, 1. (2010, March 23). *Public Law 111-148 - Patient Protection and Affordable Care Act*. Retrieved January 24, 2012, from U.S. Government Printing Office: http://www.gpo.gov/fdsys/pkg/PLAW-111publ148/pdf/PLAW-111publ148.pdf

Waddle, J., Evers, A., & Piccirillo, J. (1998). Postanesthesia Care Unit Length of Stay: Quantifying and Assessing Dependent Factors. *Anesthesia & Analgesia*, 628-633.

Womack, J., & Jones, D. (2003). *Lean Thinking: Banish Waste and Create Wealth in your Corporation.* New York: Free Press, A division of Simon & Schuster, Inc.